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Nakada et al.

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(54) **IMAGE-PROCESSING APPARATUS AND IMAGE-PROCESSING METHOD FOR GENERATING A VIRTUAL ANGLE OF VIEW**

(71) Applicant: **CANON KABUSHIKI KAISHA**, Tokyo (JP)

(72) Inventors: **Yuichi Nakada**, Yokohama (JP); **Yosuke Sato**, Kawasaki (JP)

(73) Assignee: **Canon Kabushiki Kaisha**, Tokyo (JP)

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(51) **Int. Cl.**

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H04N 9/09	(2006.01)
H04N 13/00	(2006.01)
H04N 5/262	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 5/23229*** (2013.01); ***H04N 5/23296*** (2013.01); ***H04N 5/2627*** (2013.01); ***H04N 9/09*** (2013.01); ***H04N 13/0011*** (2013.01)

(58) **Field of Classification Search**

USPC 348/218.1

See application file for complete search history.

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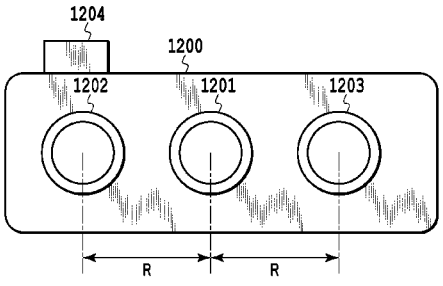
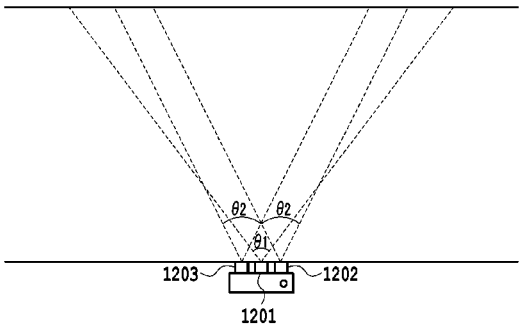
Primary Examiner — Twyler Haskins
Assistant Examiner — Akshay Trehan
(74) *Attorney, Agent, or Firm* — Fitzpatrick, Cella, Harper & Scinto

(57) **ABSTRACT**

An image-processing apparatus obtains first image data having a first angle of view and second image data having a second angle of view smaller than the first angle of view. The image-processing apparatus then generates third image data by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command and being smaller than the first angle of view but larger than the second angle of view. Weights used in this weighted combination are such that the closer the third angle of view is to the second angle of view, the larger is the weight on the second image data relative to the weight on the first image data.

16 Claims, 19 Drawing Sheets





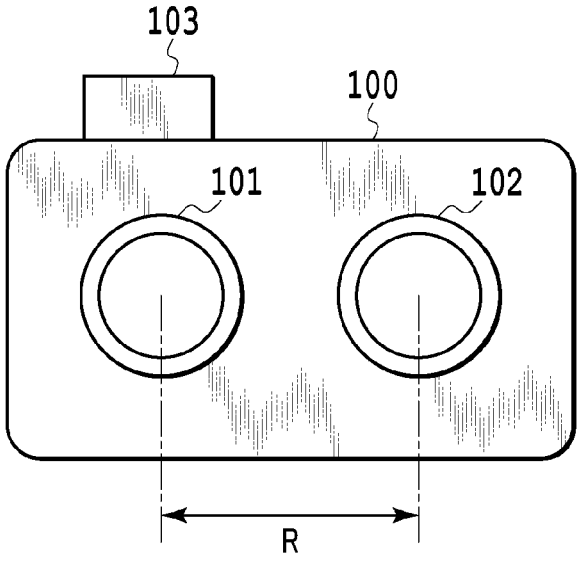

103
100
101
102
R

FIG.1A

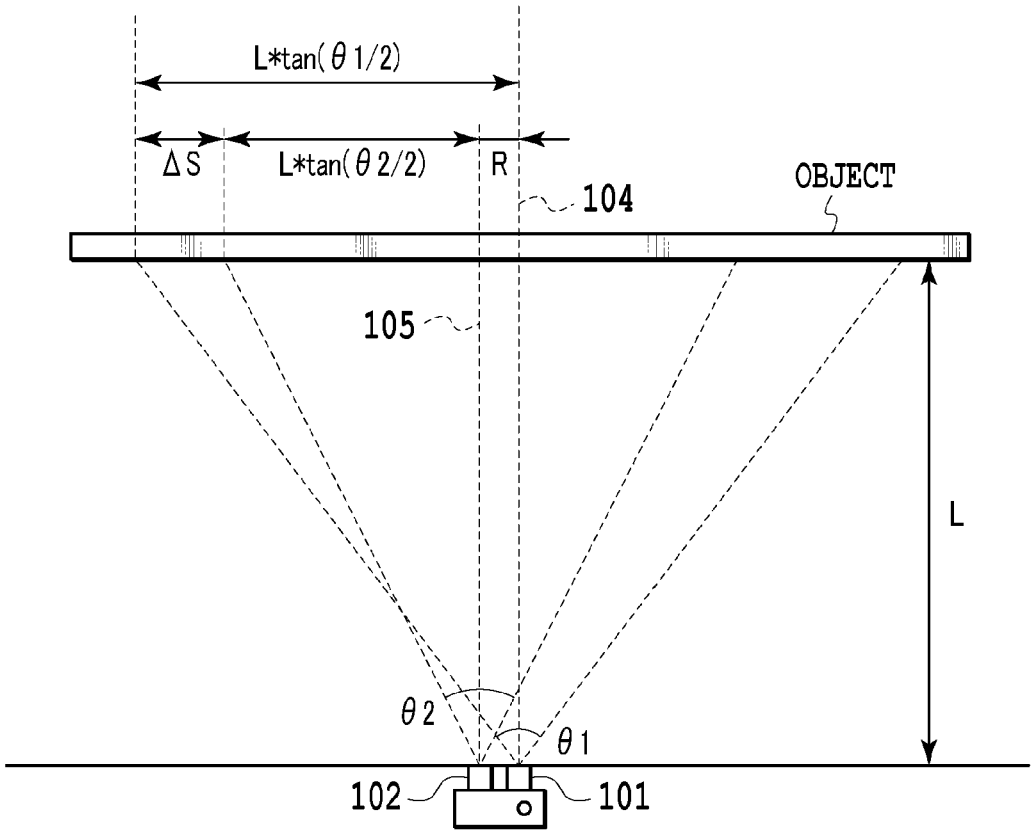

L*tan(θ1/2)
ΔS
L*tan(θ2/2)
R
104
OBJECT
105
L
θ2
θ1
102
101

FIG.1B

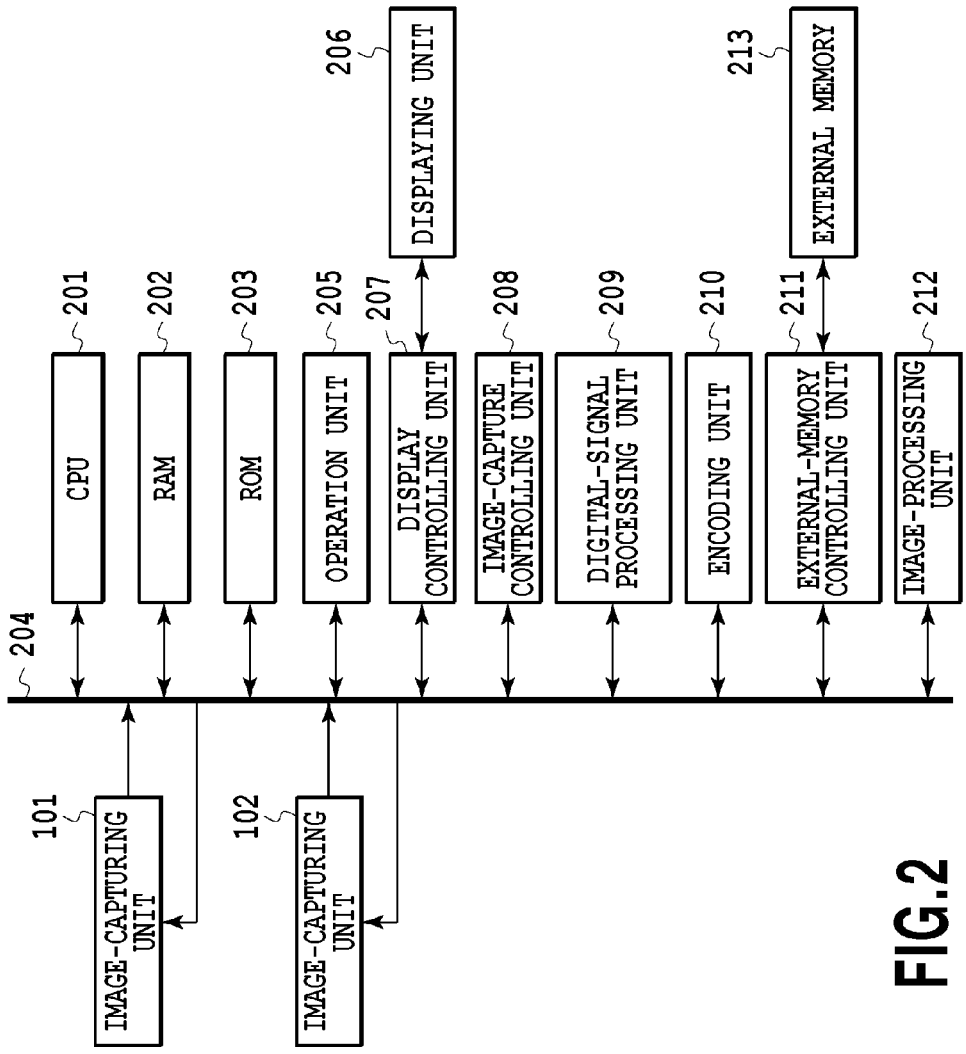

204
CPU
201
RAM
202
ROM
203
OPERATION UNIT
205
DISPLAY CONTROLLING UNIT
207
206
DISPLAYING UNIT
IMAGE-CAPTURE CONTROLLING UNIT
208
DIGITAL-SIGNAL PROCESSING UNIT
209
ENCODING UNIT
210
EXTERNAL-MEMORY CONTROLLING UNIT
211
213
EXTERNAL MEMORY
IMAGE-PROCESSING UNIT
212
101
IMAGE-CAPTURING UNIT
102
IMAGE-CAPTURING UNIT

FIG.2

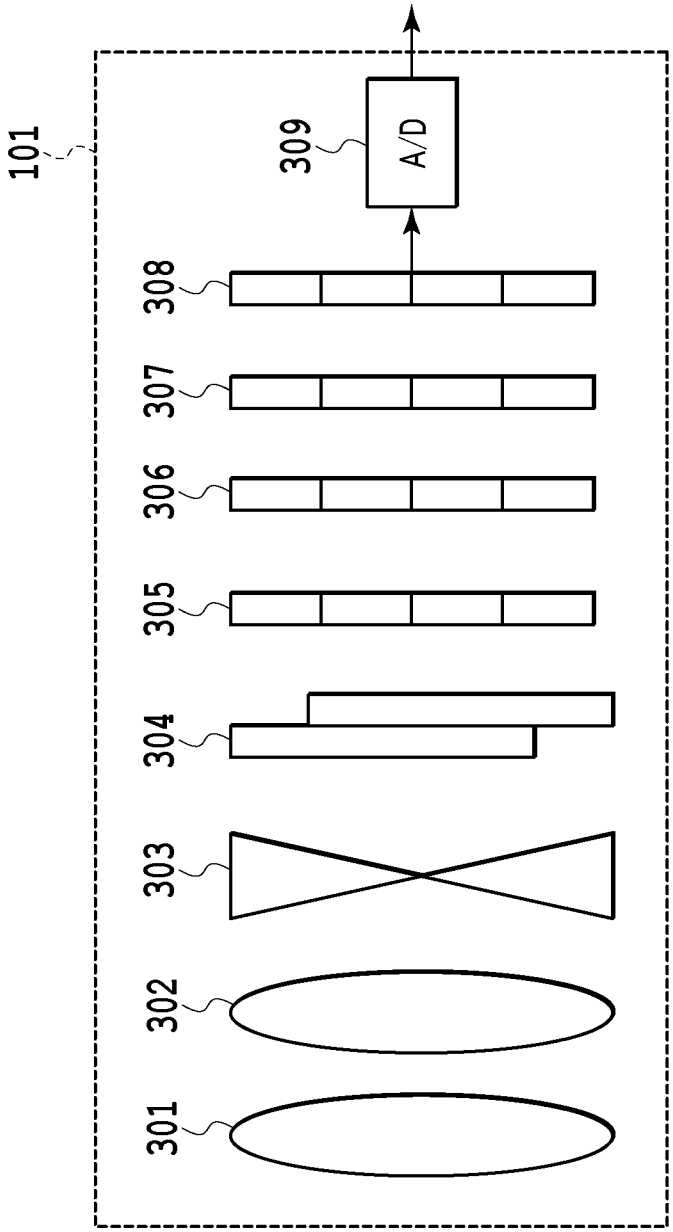


FIG.3

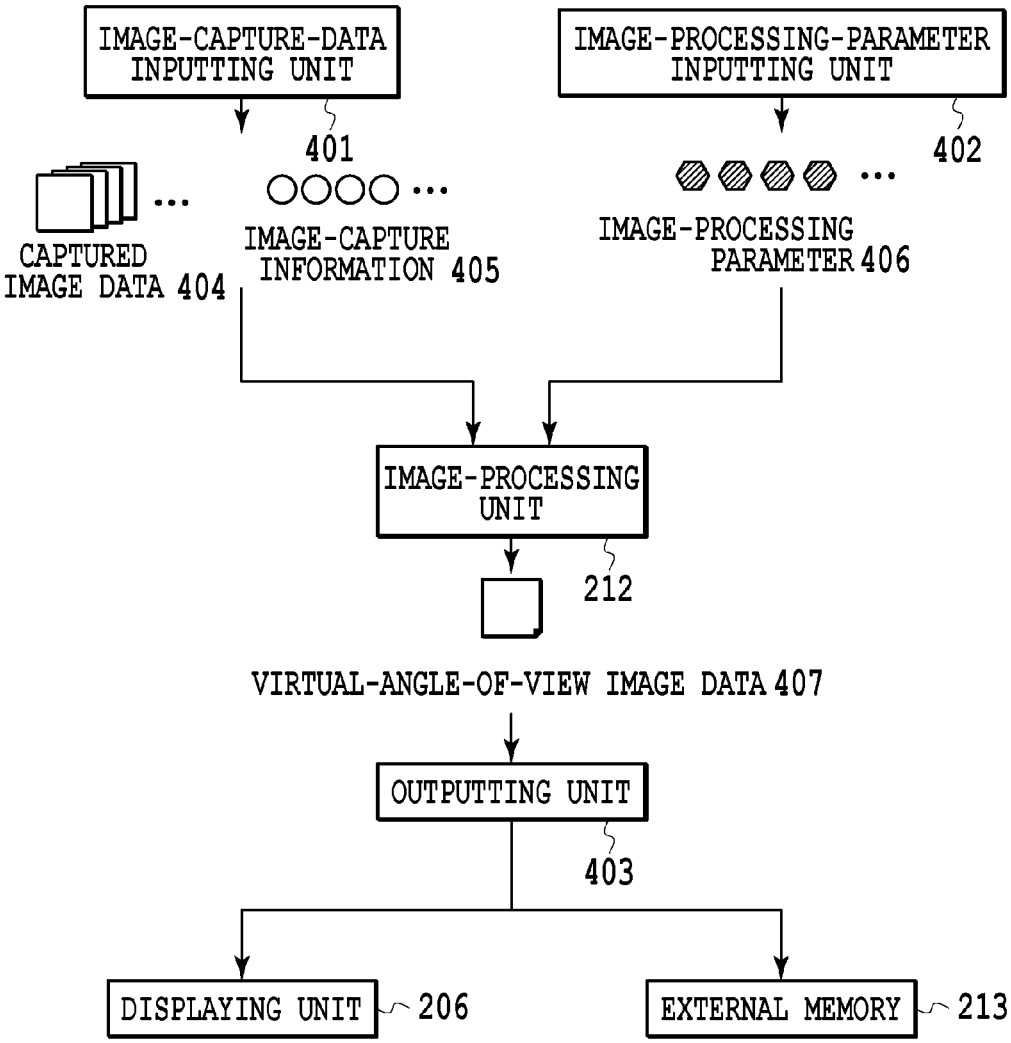


IMAGE-CAPTURE-DATA INPUTTING UNIT
401
IMAGE-PROCESSING-PARAMETER INPUTTING UNIT
402
CAPTURED IMAGE DATA 404
IMAGE-CAPTURE INFORMATION 405
IMAGE-PROCESSING PARAMETER 406
IMAGE-PROCESSING UNIT
212
VIRTUAL-ANGLE-OF-VIEW IMAGE DATA 407
OUTPUTTING UNIT
403
DISPLAYING UNIT
206
EXTERNAL MEMORY
213

FIG.4

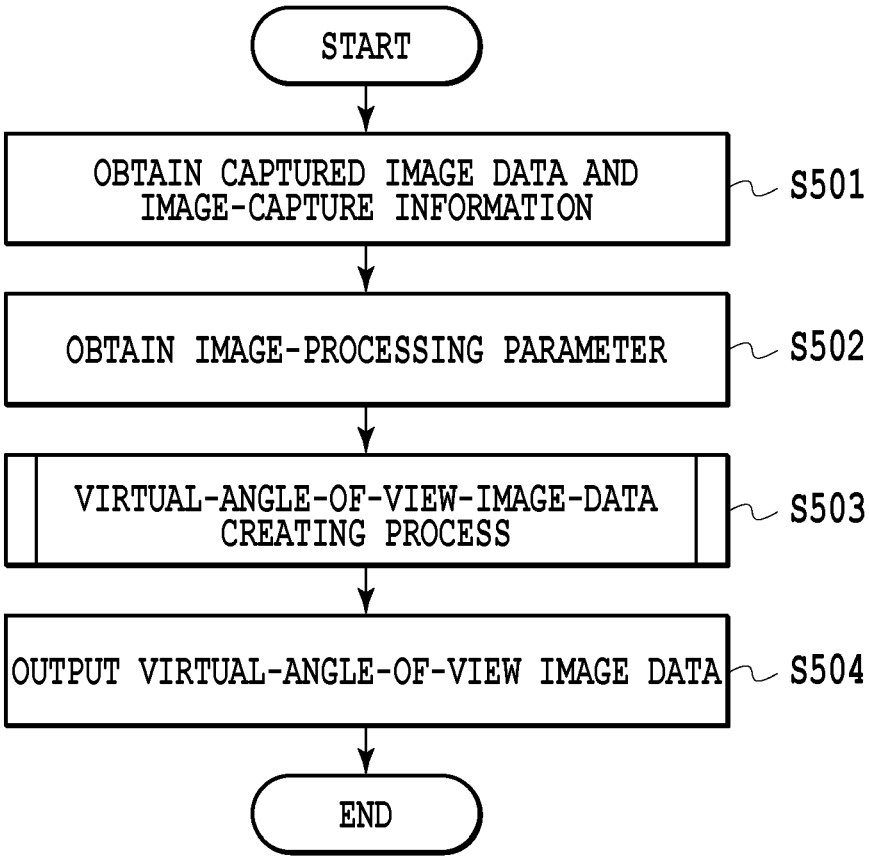

START
OBTAIN CAPTURED IMAGE DATA AND IMAGE-CAPTURE INFORMATION
S501
OBTAIN IMAGE-PROCESSING PARAMETER
S502
VIRTUAL-ANGLE-OF-VIEW-IMAGE-DATA CREATING PROCESS
S503
OUTPUT VIRTUAL-ANGLE-OF-VIEW IMAGE DATA
S504
END

FIG.5

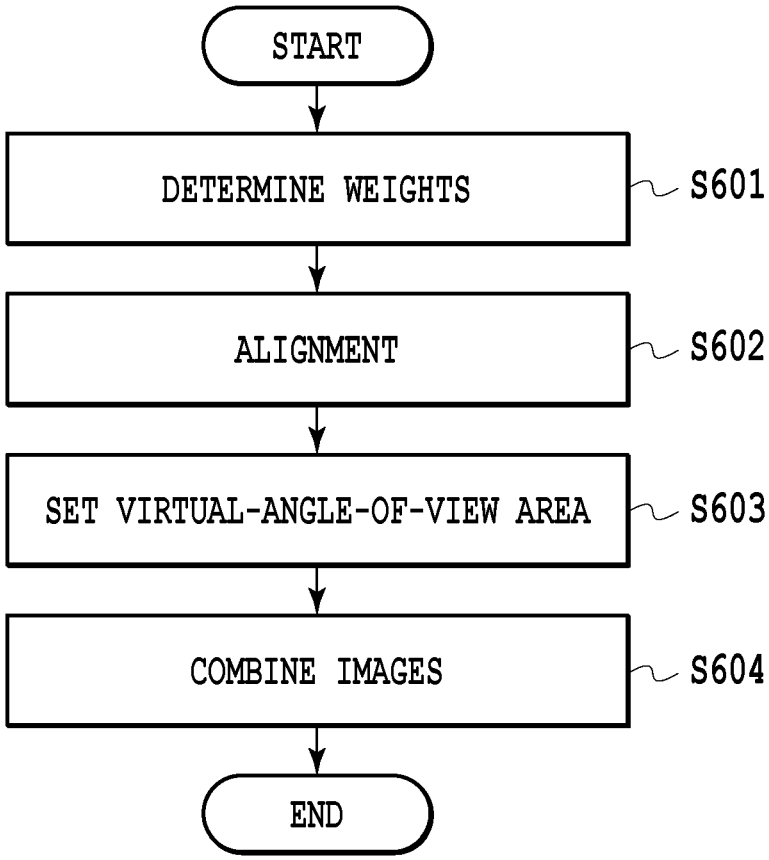

START
DETERMINE WEIGHTS
S601
ALIGNMENT
S602
SET VIRTUAL-ANGLE-OF-VIEW AREA
S603
COMBINE IMAGES
S604
END

FIG.6

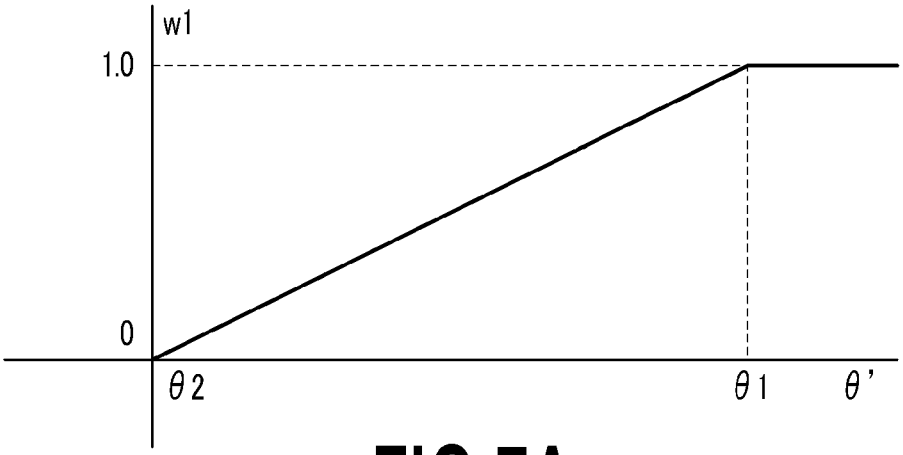


FIG.7A

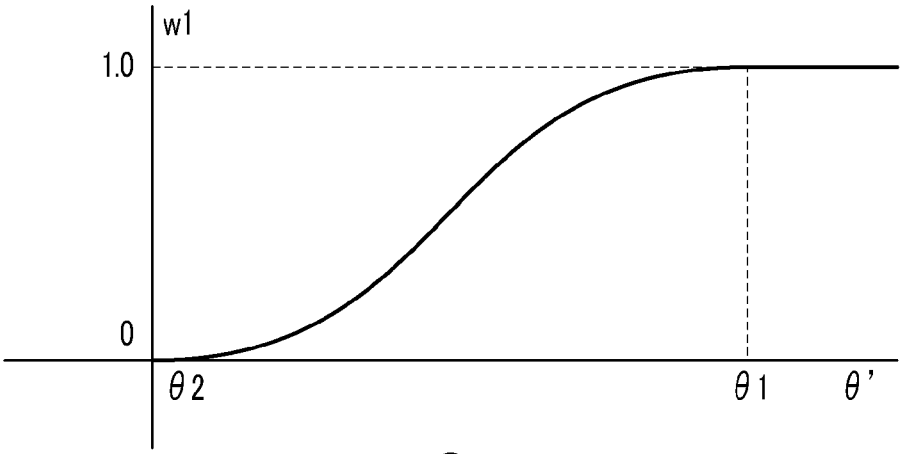


FIG.7B

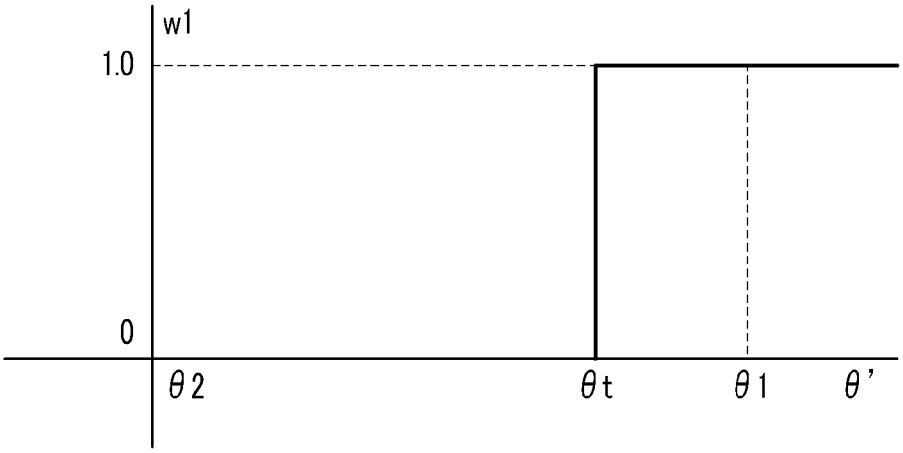


FIG.7C

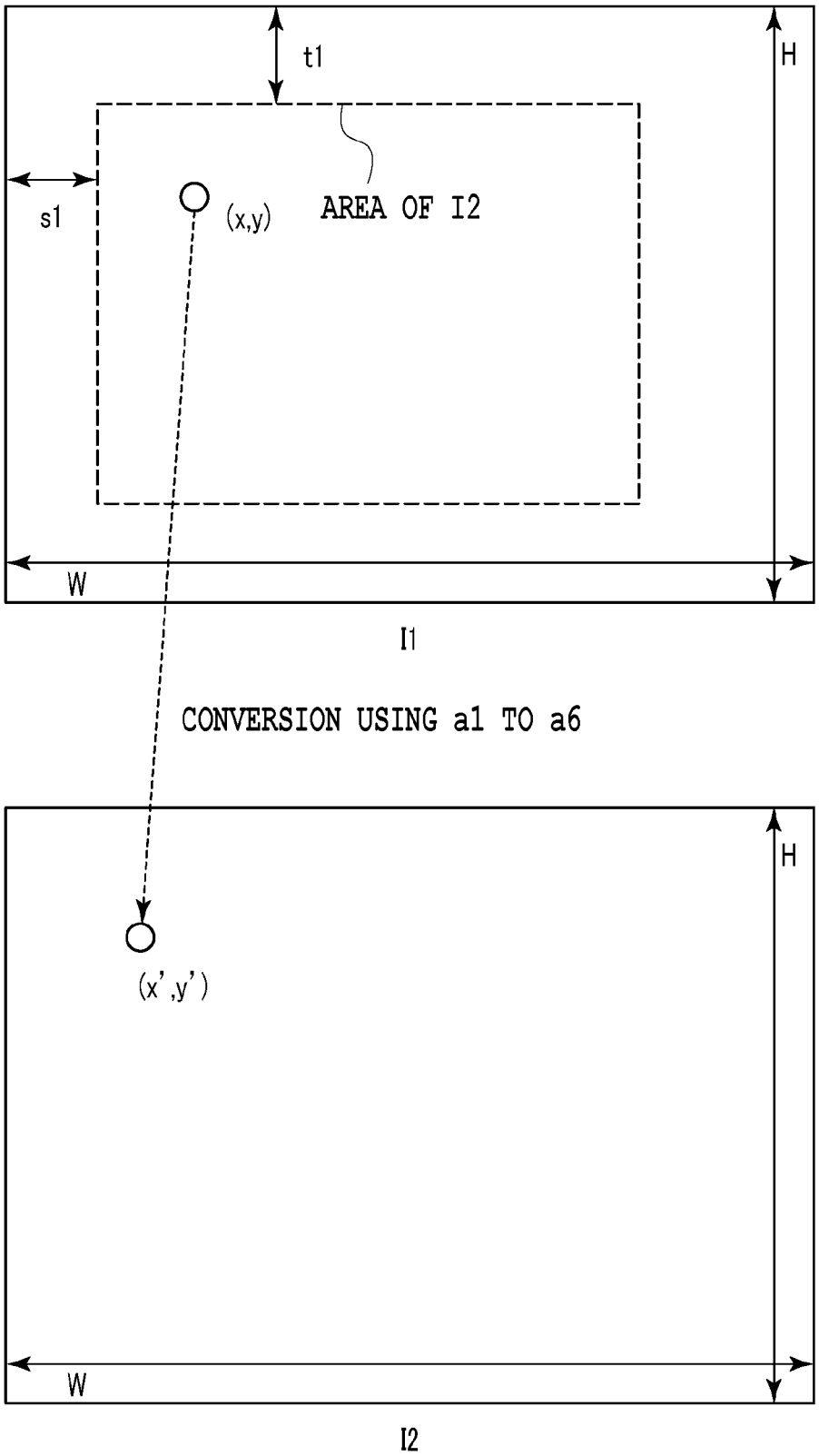


FIG.8

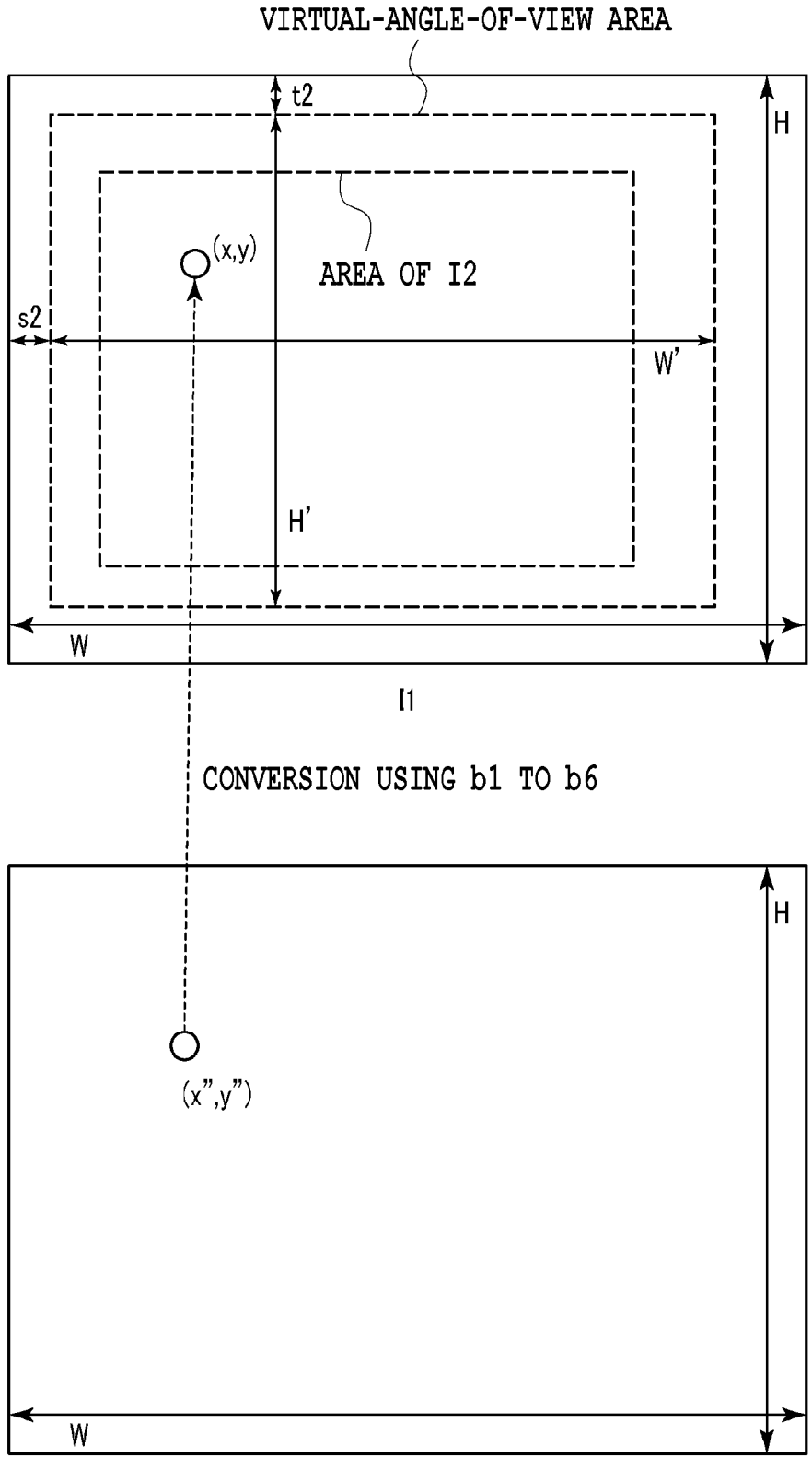

VIRTUAL-ANGLE-OF-VIEW AREA
t2
H
(x,y)
AREA OF I2
s2
W'
H'
W
I1
CONVERSION USING b1 TO b6
H
(x",y")
W
VIRTUAL-ANGLE-OF-VIEW IMAGE

FIG.9

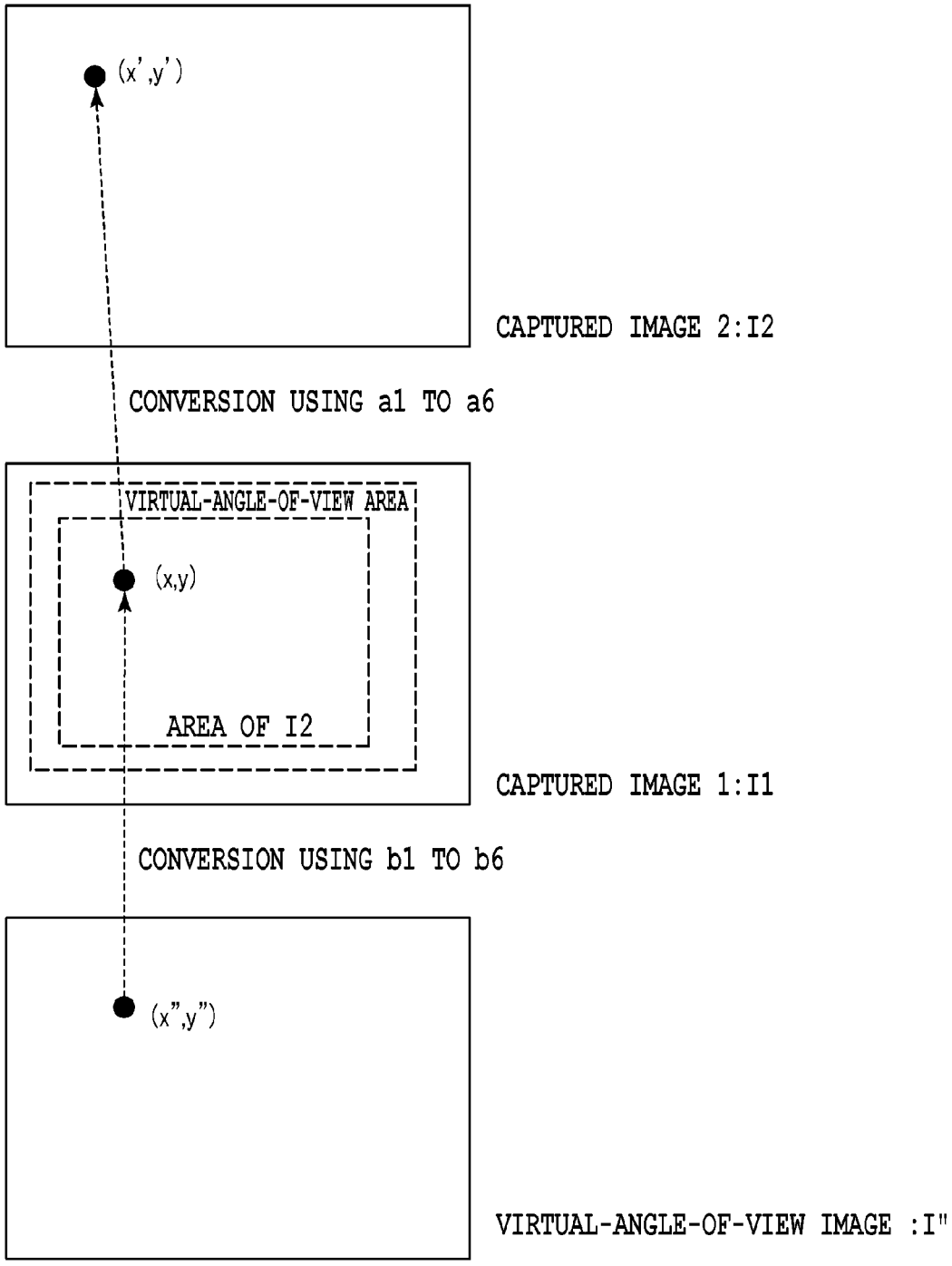

(x',y')
CAPTURED IMAGE 2:I2
CONVERSION USING a1 TO a6
VIRTUAL-ANGLE-OF-VIEW AREA
(x,y)
AREA OF I2
CAPTURED IMAGE 1:I1
CONVERSION USING b1 TO b6
(x",y")
VIRTUAL-ANGLE-OF-VIEW IMAGE :I"

FIG.10

FIG.11A

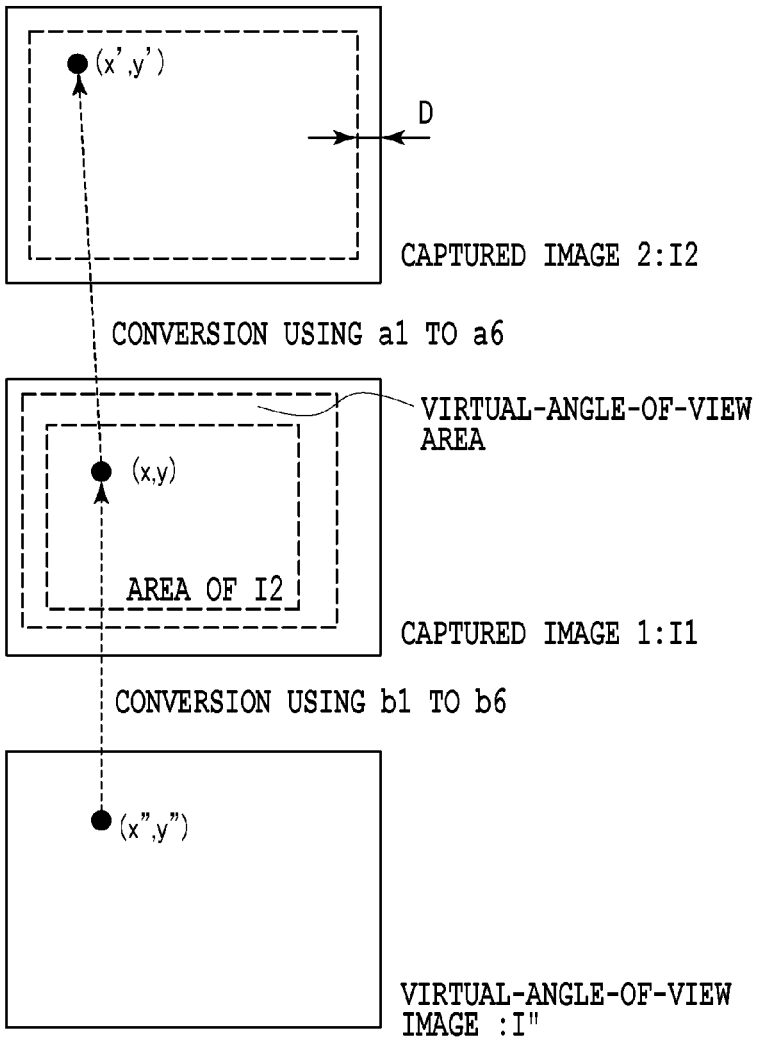
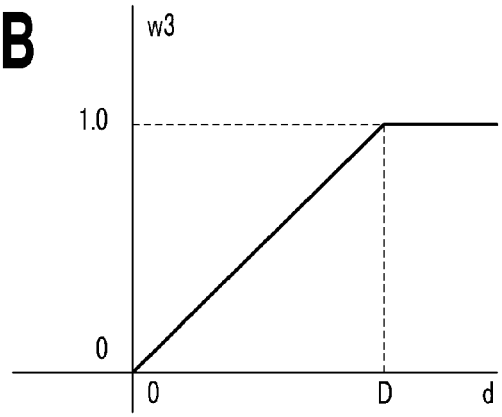


FIG.11B



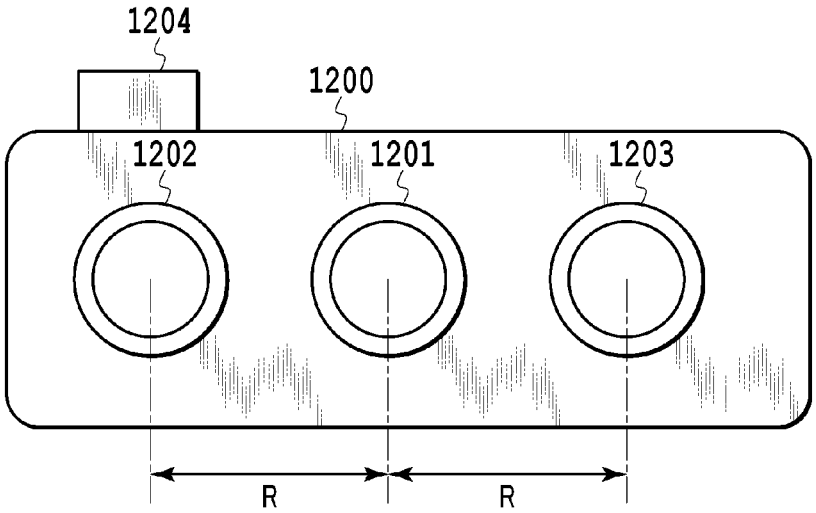


FIG.12A

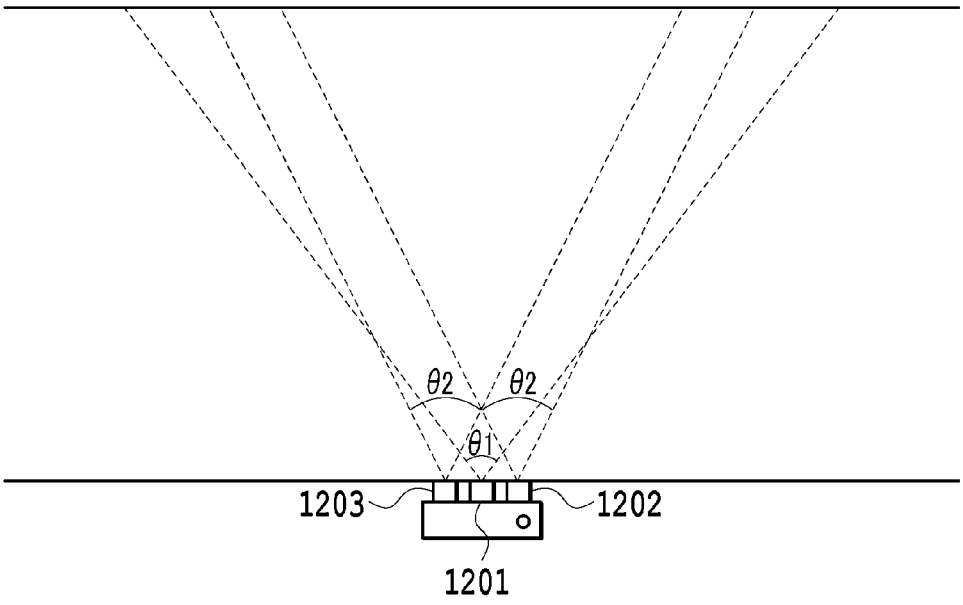


FIG.12B

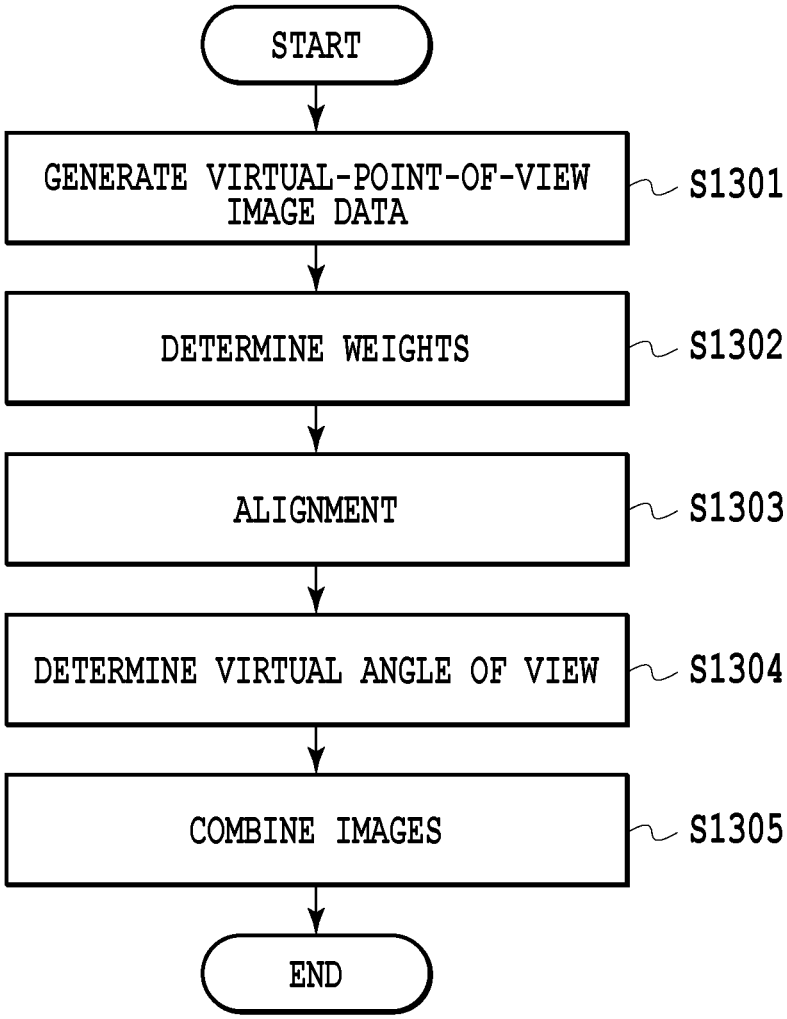

START
GENERATE VIRTUAL-POINT-OF-VIEW IMAGE DATA
S1301
DETERMINE WEIGHTS
S1302
ALIGNMENT
S1303
DETERMINE VIRTUAL ANGLE OF VIEW
S1304
COMBINE IMAGES
S1305
END

FIG.13

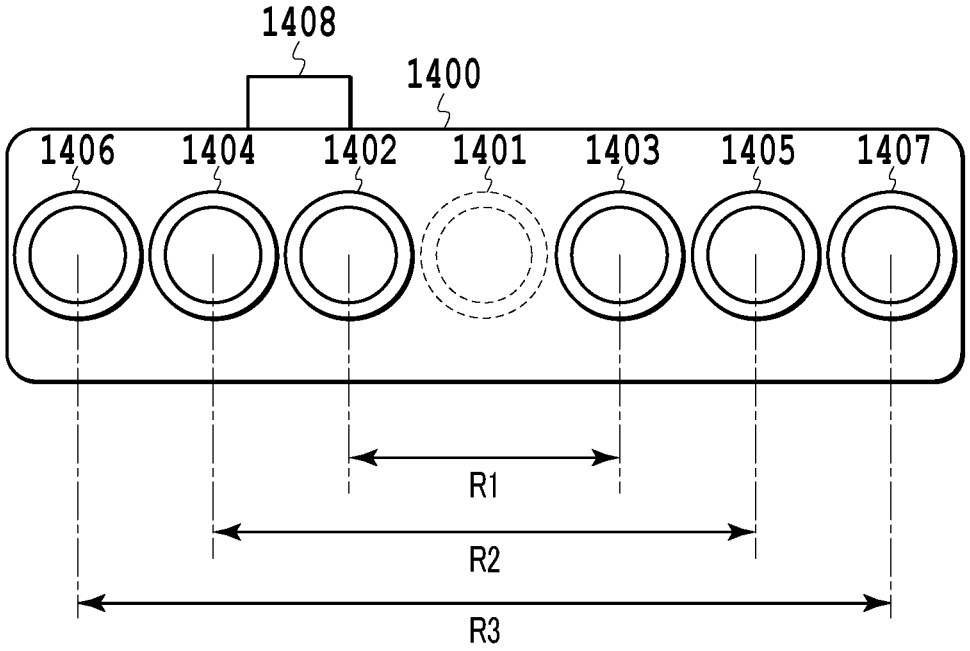


FIG.14A

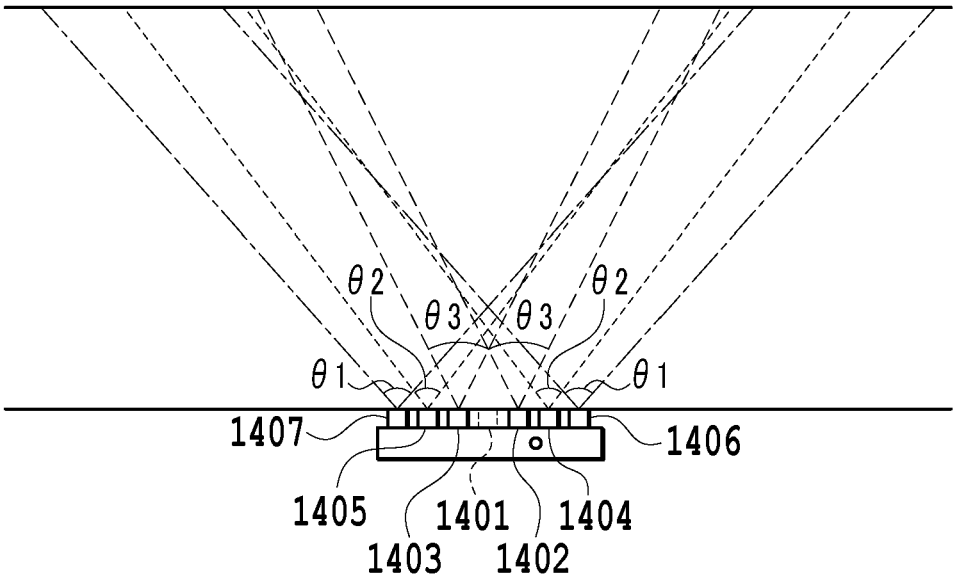


FIG.14B

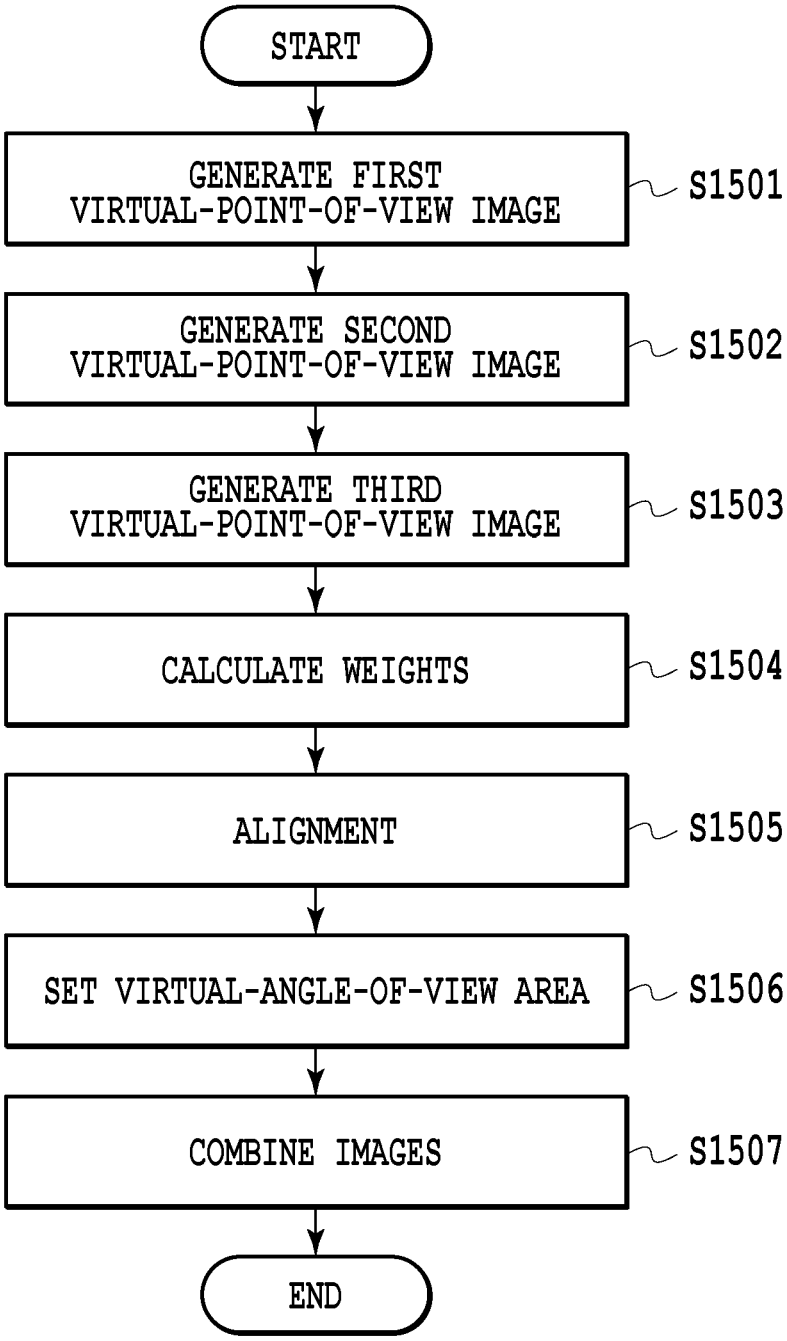

START
GENERATE FIRST VIRTUAL-POINT-OF-VIEW IMAGE
S1501
GENERATE SECOND VIRTUAL-POINT-OF-VIEW IMAGE
S1502
GENERATE THIRD VIRTUAL-POINT-OF-VIEW IMAGE
S1503
CALCULATE WEIGHTS
S1504
ALIGNMENT
S1505
SET VIRTUAL-ANGLE-OF-VIEW AREA
S1506
COMBINE IMAGES
S1507
END

FIG.15

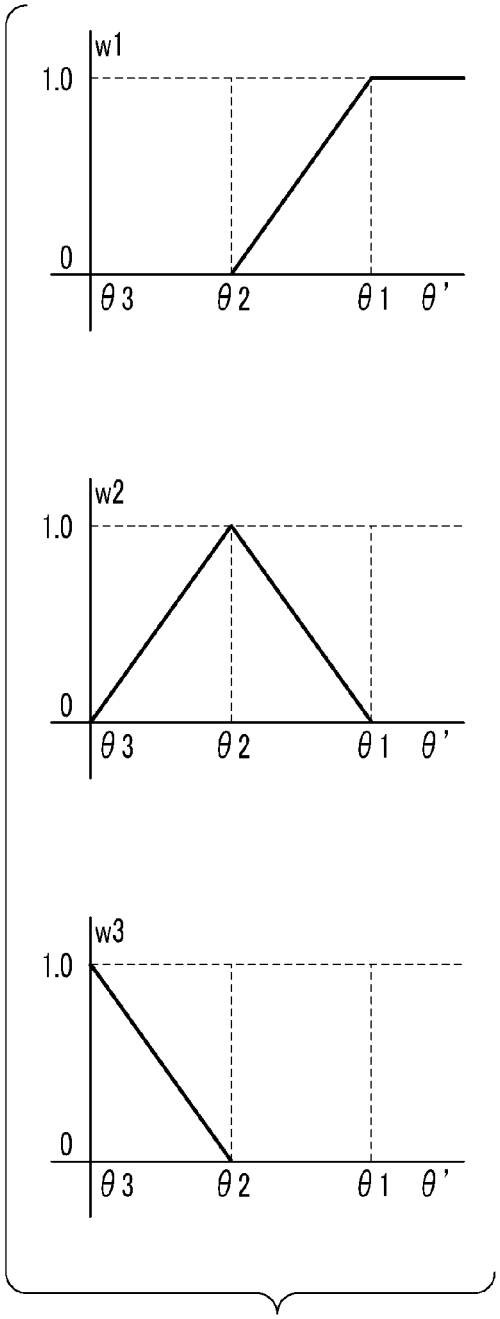


FIG.16A

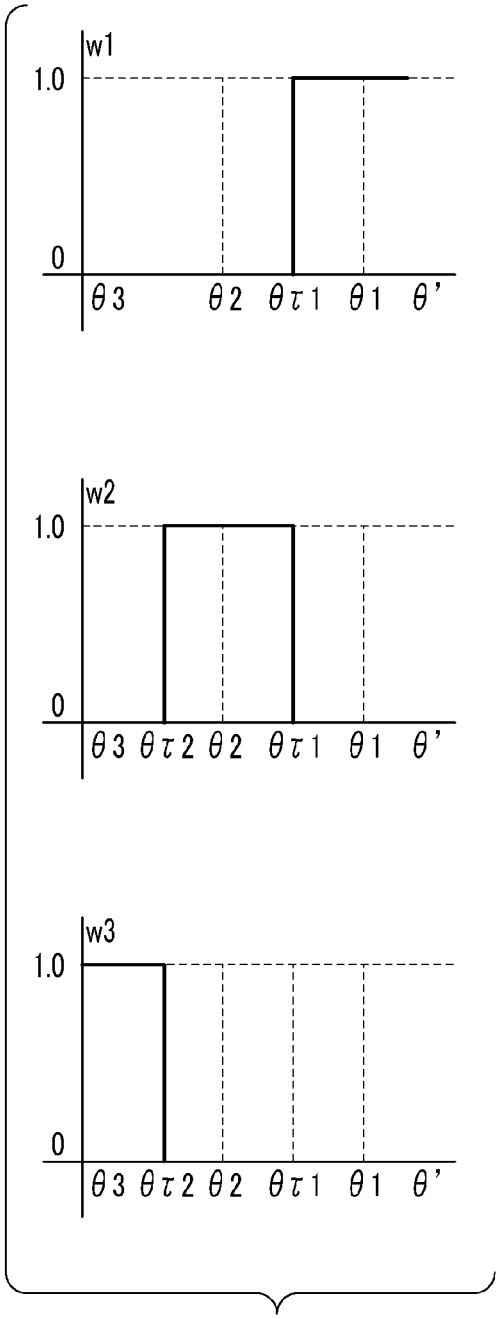


FIG.16B

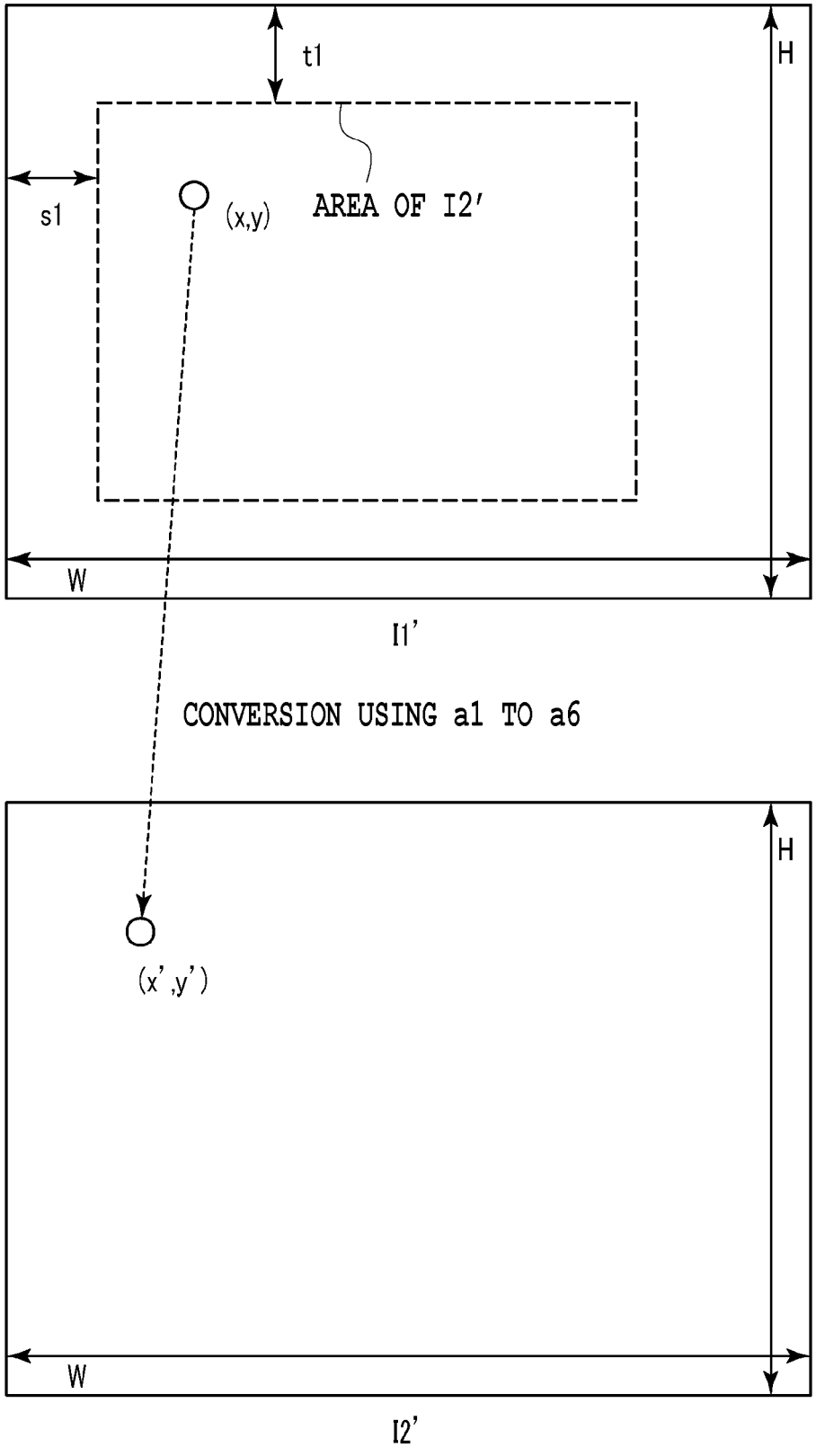


FIG.17

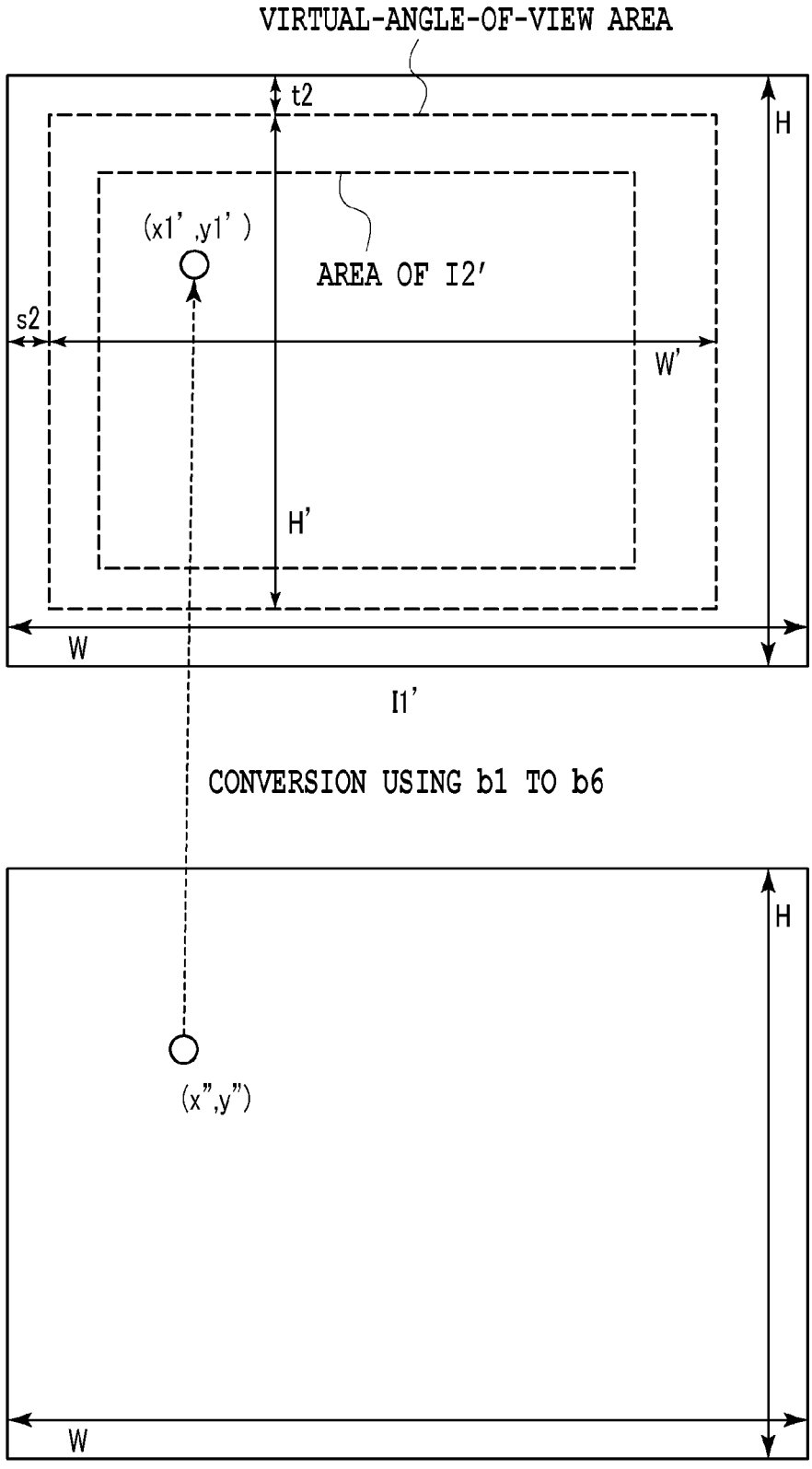

VIRTUAL-ANGLE-OF-VIEW AREA
t2
H
(x1' ,y1')
AREA OF I2'
s2
W'
H'
W
I1'
CONVERSION USING b1 TO b6
H
(x",y")
W
VIRTUAL-ANGLE-OF-VIEW IMAGE

FIG.18

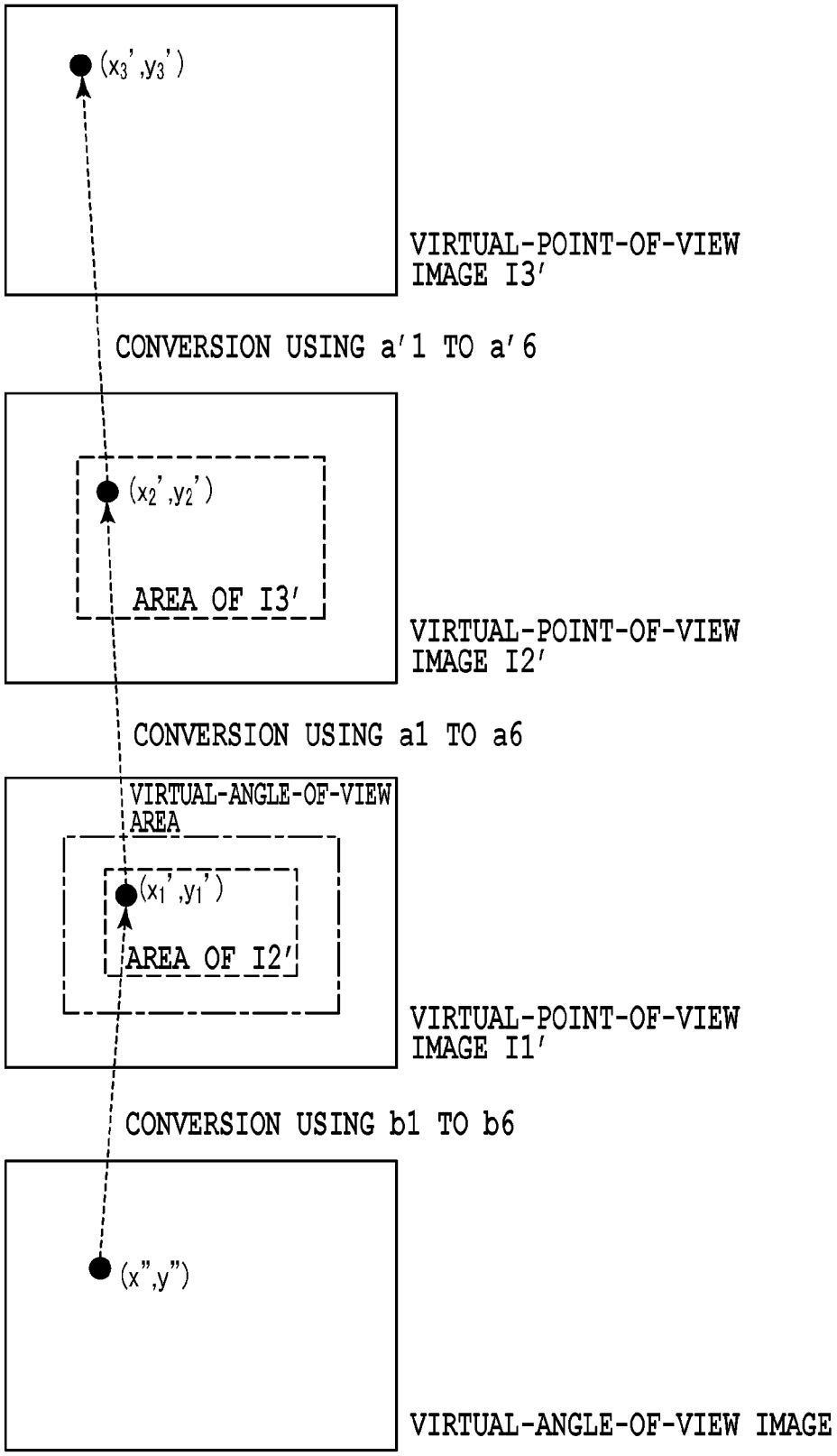

(x3',y3')
VIRTUAL-POINT-OF-VIEW IMAGE I3'
CONVERSION USING a'1 TO a'6
(x2',y2')
AREA OF I3'
VIRTUAL-POINT-OF-VIEW IMAGE I2'
CONVERSION USING a1 TO a6
VIRTUAL-ANGLE-OF-VIEW AREA
(x1',y1')
AREA OF I2'
VIRTUAL-POINT-OF-VIEW IMAGE I1'
CONVERSION USING b1 TO b6
(x",y")
VIRTUAL-ANGLE-OF-VIEW IMAGE

FIG.19

IMAGE-PROCESSING APPARATUS AND IMAGE-PROCESSING METHOD FOR GENERATING A VIRTUAL ANGLE OF VIEW

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an image-processing apparatus, and an image-processing method. Specifically, the present invention relates to an image-processing apparatus, and an image-processing method which use a plurality of pieces of captured image data of different angles of view to generate image data of a different angle of view.

2. Description of the Related Art

Heretofore, there has been known a technique which realizes zoom through image processing (digital zoom) by enlarging a desired area of a captured image. This method has a problem in that, as the zoom magnification increases, the pixel-enlargement magnification increases and the perceived resolution is gradually deteriorated. To this end, there has been known a technique in which zoom based on image processing is performed without deteriorating the perceived resolution by using a plurality of cameras of different angles of view (e.g. Japanese Patent No. 4341019). Japanese Patent No. 4341019 uses an image-capturing apparatus including a camera of a wide angle of view and a camera of a narrow angle of view. In a case where the zoom magnification is low, the digital zoom process is performed by using the camera of the wide angle of view. In a case where the zoom magnification exceeds a predetermined value, the camera in use is switched, and the digital zoom process is performed using the camera of the narrow angle of view.

However, Japanese Patent No. 4341019 has a problem in that the perceived resolution greatly changes when the camera in use is switched.

SUMMARY OF THE INVENTION

In view of this, the present invention realizes digital zoom in which the perceived resolution does not deteriorate and also the perceived resolution changes smoothly.

An image-processing apparatus according to the present invention includes an obtaining unit configured to obtain first image data having a first angle of view and second image data having a second angle of view smaller than the first angle of view, and a generating unit configured to generate third image data by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command and being smaller than the first angle of view but larger than the second angle of view, the generating unit determines weights on the first image data and second image data in the weighted combination such that the closer the third angle of view is to the second angle of view, the larger is the weight on the second image data relative to the weight on the first image data, and the generating unit performs the weighted combination by using the determined weights.

The present invention can realize smooth digital zoom without deteriorating the perceived resolution.

Further features of the present invention will become apparent from the following description of exemplary embodiments (with reference to the attached drawings).

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are diagrams showing an example of a multiple-lens image-capturing apparatus including a plurality of image-capturing units according to Embodiment 1 of the present invention;

FIG. **2** is a block diagram showing an example of the internal configuration of the multiple-lens image-capturing apparatus;

FIG. **3** is a diagram showing an example of the internal configuration of each image-capturing unit;

FIG. **4** is a diagram showing a schematic functional configuration according to Embodiment 1 of the present invention;

FIG. **5** is a flowchart showing the operations in an entire process according to Embodiment 1 of the present invention;

FIG. **6** is a flowchart showing the operations in a virtual-angle-of-view-image generating process according to Embodiment 1 of the present invention;

FIGS. **7**A to **7**C are graphs each showing the relationship between a virtual angle of view and weights according to Embodiment 1 of the present invention;

FIG. **8** is a diagram showing the correspondence between a captured image 1 and a captured image 2 according to Embodiment 1 of the present invention;

FIG. **9** is a diagram showing the correspondence between the captured image 1 and a virtual-angle-of-view image according to Embodiment 1 of the present invention;

FIG. **10** is a diagram showing the correspondence between the captured image 1 and the captured image 2 and the virtual-angle-of-view image after an image-combining process;

FIGS. **11**A and **11**B are a diagram and a graph showing the correspondence between the captured image 1 and the captured image 2 and the virtual-angle-of-view image in a case where a blending process is performed during the image-combining process;

FIGS. **12**A and **12**B are diagrams showing an example of a multiple-lens image-capturing apparatus including a plurality of image-capturing units according to Embodiment 4 of the present invention;

FIG. **13** is a flowchart showing the operations in a virtual-angle-of-view-image generating process according to Embodiment 4 of the present invention;

FIGS. **14**A and **14**B are diagrams showing an example of a multiple-lens image-capturing apparatus including a plurality of image-capturing units according to Embodiment 5 of the present invention;

FIG. **15** is a flowchart showing the operations in a virtual-angle-of-view-image generating process according to Embodiment 5 of the present invention;

FIGS. **16**A and **16**B are sets of graphs each showing the relationship between a virtual angle of view and weights in Embodiment 5 of the present invention;

FIG. **17** is a diagram showing the correspondence between a virtual-point-of-view image I1' and a virtual-point-of-view image I2' in Embodiment 5 of the present invention;

FIG. **18** is a diagram showing the correspondence between the virtual-point-of-view image I1' and a virtual-angle-of-view image in Embodiment 5 of the present invention; and

FIG. **19** is a diagram showing the corresponding between the virtual-point-of-view image I1' and the virtual-point-of-view image I2' and a virtual-point-of-view image I3' and the virtual-angle-of-view image after an image-combining process of the present invention.

DESCRIPTION OF THE EMBODIMENTS

Hereinbelow, embodiments of the invention will be described in detail with reference to the drawings. Note that

the following embodiments are mere illustration of examples and are not intended to limit the scope of the present invention.

Embodiment 1

In this embodiment, virtual-angle-of-view image data corresponding to a virtual angle of view selected by the user is generated based on two pieces of captured image data of different angles of view and on the virtual angle of view. In this process, virtual-angle-of-view image data of a small zoom magnification can be obtained by setting the virtual angle of view to a large value, and virtual-angle-of-view image data of a large zoom magnification can be obtained by setting the virtual angle of view to a small value. In other words, by changing the virtual angle of view, the user can change the zoom magnification of the virtual-angle-of-view image data. This embodiment can be utilized as a process for generating preview image data at the time of image capture or as a process for generating image data zoomed with a given magnification after image capture.

FIGS. **1**A and **1**B are diagrams showing an example of a multiple-point-of-view image-capturing apparatus according to a multiple-lens system including a plurality of image-capturing units. As shown in FIG. **1**A, an image-capturing apparatus **100** includes two image-capturing units **101**, **102** configured to obtain color image data, and an image-capturing button **103**. As shown in FIG. **1**B, the image-capturing unit **101** and the image-capturing unit **102** are disposed in such a way as to have their respective optical axes **104**, **105** in parallel with each other. In this embodiment, the horizontal gap between the image-capturing unit **101** and the image-capturing unit **102** is R, the vertical gap therebetween is T, the horizontal angle of view of the image-capturing unit **101** is $\theta 1$, the vertical angle of view thereof is $\phi 1$, the horizontal angle of view of the image-capturing unit **102** is $\theta 2$, and the vertical angle of view thereof is $\phi 2$. Note that the horizontal angles of view satisfy $\theta 1 > \theta 2$, and the vertical angles of view satisfy $\phi 1 > \phi 2$. Thus, the image-capturing unit **101** has wider angles of view than the image-capturing unit **102**. As the user presses the image-capturing button **103**, the image-capturing units **101**, **102** receive light at their sensors (image-capturing devices) as optical information on an object. The optical signals thus received are A/D converted, and a plurality of pieces of digital data (captured image data) are obtained simultaneously. A distance L from the image-capturing apparatus **100** to the object calculated based on the focus settings at the time of the image capture and the like is attached to each piece of the captured image data as tag information.

With the multiple-lens image-capturing apparatus configured as above, it is possible to obtain pieces of captured image data on the same object captured from a plurality of points of view. Note that although the number of image-capturing units is two here, the number of image-capturing units is not limited to two. This embodiment is applicable regardless of the number as long as the image-capturing apparatus includes a plurality of image-capturing units.

FIG. **2** is a block diagram showing the internal configuration of the image-capturing apparatus **100**. A central processing unit (CPU) **201** is configured to integrally control units to be described below. A RAM **202** functions as the main memory, work area, and the like of the CPU **201**. A ROM **203** is configured to store a control program to be executed by the CPU **201** and the like.

A bus **204** functions as a transfer path for various kinds of data. For example, captured image data obtained by the image-capturing units **101**, **102** are sent to predetermined processing units through this bus **204**. An operation unit **205** is configured to receive the user's commands. Specifically, the operation unit **205** includes buttons, a mode dial, and the like and is capable of receiving image-capturing commands and zooming commands. A displaying unit **206** is configured to display captured images and letters. A liquid crystal display is used, for example. The displaying unit **206** may also have a touchscreen function, in which case user commands such as image-capturing commands and zooming commands through the touchscreen can be handled as inputs of the operation unit **205**.

A display controlling unit **207** is configured to control display of images and letters to be displayed on the displaying unit **206**. An image-capture controlling unit **208** is configured to control each image-capturing unit based on commands from the CPU **201** such as focusing the lens, opening/closing the shutter, and adjusting the diaphragm. A digital-signal processing unit **209** is configured to perform various processes such as white balancing, gamma correction, and noise reduction on captured image data received through the bus **204**.

An encoding unit **210** is configured to perform a process for converting captured image data into a file format such as JPEG or MPEG. An external-memory controlling unit **211** is an interface for connecting the image-capturing apparatus **100** to an external memory **213** (e.g. PC, hard disk drive, memory card, CF card, SD card, and USB memory). An image-processing unit **212** is configured to perform image processing such as image combination by using pieces of captured image data obtained by the image-capturing units **101**, **102** or by using pieces of captured image data outputted from the digital-signal processing unit **209**. For example, the image-processing unit **212** generates virtual-angle-of-view image data corresponding to a virtual angle of view set by the user's zooming command, by using a plurality of pieces of image data of different angles of view and the virtual angle of view.

Note that there are other constituent components of the image-capturing apparatus besides the above. However, since they are not key parts of this embodiment, their description is omitted here.

FIG. **3** is a diagram showing the internal configuration of the image-capturing unit **101**. The image-capturing unit **101** includes lenses **301**, **302**, a diaphragm **303**, a shutter **304**, an optical low-pass filter **305**, an IR-cut filter **306**, a color filter **307**, a sensor **308**, and an A/D converter **309**. The lenses **301**, **302** are a focus lens **301** and a blur-correcting lens **302**, respectively. The sensor **308** is a sensor such for example as a CMOS or CCD sensor and is configured to detect the amount of light from an object focused thereon by the above lenses. The amount of light thus detected is outputted as analog values from the sensor **308**, converted into digital values by the A/D converter **309**, and outputted as digital data to the bus **204**. Note that the image-capturing unit **102** can have a similar configuration as well.

Next, a schematic functional configuration used in a case of performing a series of processes according to this embodiment will be described with reference to FIG. **4**. An image-capture-data inputting unit **401** as a functional part of the CPU **201** obtains a plurality of pieces of captured image data **404** captured by the image-capturing units **101**, **102** from the image-capturing units **101**, **102**. Alternatively, the image-capture-data inputting unit **401** may, for example, obtain pieces of captured image data **404** which are stored in advance in the RAM **202**, the external memory **213**, or the like. Moreover, the image-capture-data inputting unit **401**

obtains image-capture information **405** including the angles of view θ1, ϕ1 of the image-capturing unit **101**, the angles of view θ2, ϕ2 of the image-capturing unit **102**, and the gap R between the image-capturing unit **101** and the image-capturing unit **102**, from a storage device such as the ROM **203** or the external memory **213**.

An image-processing-parameter inputting unit **402** as a functional part of the CPU **201** obtains an image-processing parameter **406** including a virtual angle of view θ' from the storage device such as the ROM **203** or the external memory **213**. Note that the virtual angle of view θ' is determined according to the user's zooming command received through the operation unit **205** or the like, and is stored in the storage device. The image-processing unit **212** generates virtual-angle-of-view image data **407** corresponding to the virtual angle of view θ', which is included in the image-processing parameter **406**, based on the plurality of pieces of captured image data **404**, the image-capture information **405**, and the virtual angle of view θ'. Lastly, an outputting unit **403** as a functional part of the CPU **201** outputs the virtual-angle-of-view image data **407** to the displaying unit **206** and the external memory **213**.

FIG. **5** is a flowchart showing the sequence of operations in a series of processes performed in an image-processing apparatus of this embodiment. Specifically, the processes are executed by loading a program in which the sequence shown in the flowchart in FIG. **5** is described into the RAM **202** from the ROM **203** and then by causing the CPU **201** to execute this program.

Each process shown in FIG. **5** will be described below. First, in an image-data obtaining process in step S**501**, the image-capture-data inputting unit **401** obtains a plurality of pieces of captured image data **404** captured by the image-capturing units **101**, **102** from the image-capturing units **101**, **102**. The captured image data **404** thus obtained is stored into the RAM **202** or the like. Alternatively, the captured image data **404** may be held in advance in the external memory **213** or the like and then obtained by the image-capture-data inputting unit **401**. The image-capture-data inputting unit **401** also obtains the image-capture information **405** including the angles of view θ1, ϕ1 of the image-capturing unit **101**, the angles of view θ2, ϕ2 of the image-capturing unit **102**, and the gap R between the image-capturing unit **101** and the image-capturing unit **102**, from the storage device such as the ROM **203** or the external memory **213**.

Then, in an image-processing-parameter obtaining process (virtual-angle-of-view obtaining process) in step S**502**, the image-processing-parameter inputting unit **402** obtains the image-processing parameter **406** including the virtual angle of view θ' from the storage device such as the ROM **203** or the external memory **213**.

Then, in step S**503**, the image-processing unit **212** generates virtual-angle-of-view image data **407** by using the captured image data **404** and the image-capture information **405** stored in step S**501** and the image-processing parameter **406** obtained in step S**502**. The virtual-angle-of-view image data **407** thus generated is stored into the RAM **202** or the like. The process in step S**503** will be described later in detail.

Lastly, in step S**504**, the outputting unit **405** outputs the virtual-angle-of-view image data **407** stored in step S**503** to the displaying unit **206** and the external memory **213**. By outputting the virtual-angle-of-view image data **407** to the displaying unit **206**, an image represented by the virtual-angle-of-view image data **407** can be displayed. By outputting the virtual-angle-of-view image data **407** to the external memory **213**, the virtual-angle-of-view image data **407** can be stored in the external memory.

<Virtual-Angle-of-View-Image-Data Generating Process>

In this section, the virtual-angle-of-view-image-data generating process performed in step S**503** will be described. In the virtual-angle-of-view-image-data generating process, the virtual-angle-of-view image data **407** is generated by using the captured image data **404** and the image-capture information **405** obtained in step S**501** and the image-processing parameter **406** obtained in step S**502**. Details of the virtual-angle-of-view-image-data generating process will be described below with reference to a flowchart shown in FIG. **6**.

First, in step S**601**, the image-processing unit **212** determines weights based on the angle of view θ1 of the image-capturing unit **101** and the angle of view θ2 of the image-capturing unit **102** included in the image-capture information **405** and the virtual angle of view θ' included in the image-processing parameter **406**. The weights thus determined are weights to be applied to the pieces of captured image data **404** for the virtual-angle-of-view image data **407** to be generated. In the following, captured images represented by the pieces of captured image data captured by the image-capturing units **101**, **102** will be denoted by I1, I2, respectively. As mentioned earlier, the image-capturing unit **101** has wider angles of view than the image-capturing unit **102**. Thus, the captured image I1 has wider angles of view than the captured image I2. Moreover, the weights to be applied to the captured images I1, I2 will be denoted by w1, w2, respectively. FIG. **7**A shows an example of the relationship between the virtual angle of view θ' and the weights w1, w2. In FIG. **7**A, the weights w1, w2 are determined such that the larger the value of the virtual angle of view θ', the larger the value of the weight w1. Specifically, the weights w1, w2 are described by the following equations.

$$w1 = \frac{\theta' - \theta 2}{\theta 1 - \theta 2} \tag{1}$$

$$w2 = 1 - w1$$

The weights w1, w2 thus determined are stored into a storage device such as the RAM **202**.

Then, in step S**602**, the image-processing unit **212** aligns the captured image I1 and the captured image I2. Specifically, the pixels (x,y) of the captured image I1 and the pixels (x',y') of the captured image I2 are associated with each other by using affine parameters a1 to a6 such that the object in the captured image I1 and the object in the captured image I2 overlap each other. The relationships between the pixels (x,y) and the pixels (x',y') and the affine parameters a1 to a6 are described by the following equations.

$$x' = a1x + a2y + a3$$

$$y' = a4x + a5y + a6 \tag{2}$$

An example of the method of determining the affine parameters a1 to a6 will be described below. Here, the affine parameters a1 to a6 are determined according to the following equations based on the angles of view θ1, ϕ1 of the image-capturing unit **101**, the angles of view θ2, ϕ2 of the

image-capturing unit **102**, the distance L to the object, and the gap R between the image-capturing units.

$$a1 = \frac{\tan(\theta 2/2)}{\tan(\theta 1/2)} \quad (3)$$
$$a3 = s1$$
$$a5 = \frac{\tan(\phi 2/2)}{\tan(\phi 1/2)}$$
$$a6 = t1$$
$$a2 = a4 = 0$$

Here, as shown in FIG. **8**, s1, t1 correspond respectively to the distances from the area of the captured image I2 in the captured image I1 to ends of the captured image I1 after the alignment, and can be found by the following equations. See also FIG. **1**B.

$$s1 = \frac{W}{2L\tan(\theta 1/2)}\Delta S \quad (4)$$
$$t1 = \frac{H}{2L\tan(\phi 1/2)}\Delta T$$

Here, W, H denote the width and height of the captured image I1, respectively. Moreover, ΔS, ΔT denote the lengths of cut portions the object and can be found by the following equations.

$$\Delta S = L\left(\tan\left(\frac{\theta 1}{2}\right) - \tan\left(\frac{\theta 2}{2}\right)\right) - R \quad (5)$$
$$\Delta T = L\left(\tan\left(\frac{\phi 1}{2}\right) - \tan\left(\frac{\phi 2}{2}\right)\right) - T$$

The affine parameters a1 to a6 determined as described above are stored into the storage device such as the RAM **202**.

Then, in step S**603**, the image-processing unit **212** sets a virtual-angle-of-view area in the captured image I1 based on the virtual angle of view θ' included in the image-processing parameter **406**. Specifically, as shown in FIG. **9**, the image-processing unit **212** determines affine parameters b1 to b6 which indicate the relationship between the pixels (x, y) of the captured image I1 and the pixels (x", y") of the virtual-angle-of-view image data **407**. Equations therefor are shown below.

$$x = b1x'' + b2y'' + b3$$
$$y = b4x'' + b5y'' + b6 \quad (6)$$

An example of the method of determining the affine parameters b1 to b6 will be described below. Here, the affine parameters b1 to b6 are determined according to the following equations based on the angles of view of the captured image I1, the angles of view of the virtual-angle-of-view image, and the size of the captured image I1.

$$b1 = \frac{W'}{W} \quad (7)$$
$$b3 = s2$$
$$b5 = \frac{H'}{H}$$
$$b6 = t2$$
$$b2 = b4 = 0$$

Here, W', H' denote the width and height of the virtual-angle-of-view area in the captured image I1, respectively. Moreover, s2, t2 correspond respectively to the distances from the virtual-angle-of-view area shown in FIG. **9** to the ends of the captured image I1, and can be found by the following equations, for example.

$$s2 = \frac{W}{2}\left(1 - \frac{\tan(\theta'/2)}{\tan(\theta 1/2)}\right) \quad (8)$$
$$t2 = \frac{H}{2}\left(1 - \frac{\tan(\phi'/2)}{\tan(\phi 1/2)}\right)$$

The affine parameters b1 to b6 determined as described above are stored into the storage device such as the RAM **202**.

Lastly, in step S**604**, the image-processing unit **212** generates the virtual-angle-of-view image data **407** from the captured image data **404**. In step S**604**, the virtual-angle-of-view image data **407** is generated by using the weights w1, w2 stored in step S**601**, the affine parameters a1 to a6 stored in step S**602**, and the affine parameters b1 to b6 stored in step S**603**. Specifically, the virtual-angle-of-view image data **407** is generated by finding weighted means of the captured images I1, I2 according to the following equations.

$$I''(x'', y'') = \begin{cases} (1-w2)I1(x, y) + w2I2(x', y') & \text{if } (x', y') \text{ is included in caputed image } I2 \\ I1(x, y) & \text{if } (x', y') \text{ is not included in captured image } I2 \end{cases} \quad (9)$$

Here, I" is the virtual-angle-of-view image represented by the virtual-angle-of-view image data **407**. FIG. **10** is a diagram showing the correspondence between the captured image I1 and the captured image I2 and the virtual-angle-of-view image I" after the image-combining process. The pixels (x",y") of the virtual-angle-of-view image I" are determined from the pixels (x,y) of the captured image I1 and the affine parameters b1 to b6. Moreover, the pixels (x',y') of the captured image I2 corresponding to the pixels (x",y") of the virtual-angle-of-view image I" are determined from the pixels (x,y) of the captured image I1 and the affine parameters a1 to a6. The virtual-angle-of-view image data **407** representing the virtual-angle-of-view image I" is generated from the captured images I1, I2 by using the above relationships. The virtual-angle-of-view image data **407** thus generated is stored into the storage device such as the RAM **202**. By the above step, the virtual-angle-of-view-image generating process is finished.

By performing the processes and control described above, virtual-angle-of-view image data corresponding to a given virtual angle of view can be generated. By generating and displaying virtual-angle-of-view image data according to the user's zooming command, digital zoom with smooth change in perceived resolution can be realized.

In this embodiment, the weights w1, w2 are linearly changed according to the value of the virtual angle of view θ' in such a way as to follow the line in FIG. **7**A. Note, however, that the relationship between the weights and the virtual angle of view is not limited to this case. For example, the weights w1, w2 may be changed according to the value of the virtual angle of view θ' as shown in FIG. **7**B. Specifically, such changes are described by the following equations.

$$w1 = \frac{1}{1 + e^{-\alpha(\theta' - \beta)}} \tag{10}$$
$$\beta = \frac{\theta 1 - \theta 2}{2}$$
$$w2 = 1 - w1$$

By using non-linear weighting as shown in FIG. **7**B, the perceived resolution can be changed more smoothly in response to the user's zooming command. Alternatively, the weights w1, w2 may be switched between 0 and 1 according to the value of the virtual angle of view θ' as shown in FIG. **7**C.

$$w1 = \begin{cases} 0 & (\theta' < \theta t) \\ 1 & (\theta t \leq \theta') \end{cases} \tag{11}$$
$$w2 = 1 - w1$$

By using weighting as shown in FIG. **7**C, the captured image I2 with higher perceived resolution, which is a part of the captured image data **404**, can be used preferentially. Accordingly, the perceived resolution of the virtual-angle-of-view image data **407** can be improved.

Moreover, although the optical axis **104** and the optical axis **105** are parallel with each other in this embodiment, this embodiment is applicable even without exact parallelism therebetween. In this case, however, the method of determining the affine parameters a1 to a6 needs to be changed. For example, a motion vector may be determined for each block of a captured image 1 and of a captured image 2, and the affine parameters a1 to a6 may be determined based on the motion vectors by using the method of least squares or the like. Alternatively, instead of affine parameters, projective transform parameters may be found based on the motion vectors to associate the captured image I1 and the captured image I2, for example.

Still alternatively, as shown in FIG. **11**A, an area separated from the end of the captured image I2 by a distance of D or shorter may be additionally set as an area for blending, and a blending process may be performed to make the boundary with the captured image I1 unnoticeable. Specifically, weighted means of the captured images I1, I2 may be found according to the following equations to generate the virtual-angle-of-view image data **407**.

$$I''(x'', y'') = \begin{cases} (1 - w2w3)I1(x, y) + w2w3I2(x', y') & \text{if}(x', y') \text{ is included in captured image } I2 \\ I1(x, y) & \text{if}(x', y') \text{ is not included in captured image } I2 \end{cases} \tag{12}$$

Here, as shown in FIG. **11**B, w3 is a weight value determined by a distance d from the pixel (x',y') of the captured image I2 to the end of the captured image I2 and is set such that the longer the distance d, the larger the weight value w3. By combining the captured images I1, I2 according to the above equations, the captured images I1, I2 can be combined such that their boundary portion is made smooth.

Embodiment 2

In Embodiment 1, the virtual-angle-of-view image data **407** is generated by using any one of the weighting methods shown in FIGS. **7**A to **7**C. In Embodiment 2, the weighting method is switched according to a mode selected by the user. In this way, virtual-angle-of-view image data **407** based on a given image-capturing mode can be generated.

In Embodiment 2, the image-capture mode can be switched between a noise-reduction priority mode and a resolution priority mode. The mode can be switched by a user operation obtained from an operation unit **205**. An example of weights in each mode will be described below. In the noise-reduction priority mode, the weights shown in FIG. **7**A or **7**B are used to perform image combination. In the resolution priority mode, the weights shown in FIG. **7**C are used to perform image combination. Thus, in the noise-reduction priority mode, a captured image I1 and a captured image I2 are averaged, so that a noise reduction effect can be achieved. Moreover, in the resolution priority mode, θt is set to be equal to θ1 (θt=θ1), so that the captured image I2 which has higher perceived resolution than the captured image I1 can be preferentially used within a range of θ1≤θ'≤θ2. In this way, the perceived resolution of the virtual-angle-of-view image data **407** can be improved.

By performing the process described above, virtual-angle-of-view image data **407** based on a given image-capturing mode can be generated.

Embodiment 3

In Embodiment 1 and Embodiment 2, the virtual-angle-of-view image data **407** is generated by using a set of weights w1, w2 for the entire image. In Embodiment 3, the weights w1, w2 are corrected based on the difference between the image data on a captured image I1 and a captured image I2 which is calculated for each divided area, and the virtual-angle-of-view image data **407** is generated by using sets of weights differing from one area to another. In this way, it is possible to suppress deterioration in perceived resolution resulting from alignment errors.

Specifically, first, a virtual-angle-of-view image represented by the virtual-angle-of-view image data **407** is divided into a plurality of rectangular areas. Then, for each of these rectangular areas, the sum of the absolute values of the differences between the pixels (x,y) of the captured image I1 and the corresponding pixels (x',y') of the captured image I2 is calculated. Thereafter, a correction process is performed on the weights w1, w2 based on the difference thus calculated. Specifically, in a case of an area with a large difference, the value of the weight w2 is corrected to be large while the value of the weight w1 is corrected to be small. In this way, in each area with a large difference, the perceived resolution becomes substantially equal to that of the captured image I2. Accordingly, it is possible to suppress deterioration in the perceived resolution of the virtual-angle-of-view image resulting from alignment errors.

Meanwhile, although the value of the weight w2 is corrected to be large and the value of the weight w1 is corrected to be small in this embodiment, the value of the weight w1 may be corrected to be large and the value of the weight w2 may be corrected to be small instead. In this case, in each area with a large difference, the perceived resolution becomes substantially equal to that of the captured image I1, but it is still possible to suppress deterioration in the perceived resolution of the virtual-angle-of-view image resulting from alignment errors.

Note that although the weights are set based on the sum of the absolute values of the differences between the pixels (x, y) of the captured image I1 and the pixels (x', y') of the captured image I2 in this embodiment, the method of determining the weights is not limited to this case. This embodiment is applicable as long as there is a value indicating the difference between the captured image I1 and the captured image I2.

By performing the processes described above, it is possible to suppress deterioration in perceived resolution resulting from alignment errors.

Embodiment 4

In Embodiments 1 to 3, the example is described in which mainly a flat-surface object is the image-capturing target, and the virtual-angle-of-view image data **407** is generated by calculating weighted means of pieces of captured image data of different angles of view captured from different positions. In Embodiment 4, virtual-point-of-view image data of an angle of view θ2 corresponding to the same point of view as captured image data of the angle of view θ1 is generated from a plurality of pieces of captured image data of an angle of view θ2. Then, virtual-angle-of-view image data is generated by adding the captured image data of the angle of view θ1 and the generated virtual-point-of-view image data of the angle of view θ2. In this way, good virtual-angle-of-view image data can be generated even from an object that has a depth.

The difference between Embodiment 4 and Embodiments 1 to 3 is the image-capturing apparatus **100** and the virtual-angle-of-view-image generating process S**503**. FIG. **12**A shows an example of the image-capturing apparatus in Embodiment 4. A casing **1200** of the image-capturing apparatus includes three image-capturing units **1201** to **1203** configured to obtain captured image data and an image-capturing button **1204**. As shown in FIG. **12**B, the image-capturing units **1201** to **1203** are disposed in such a way as to have their respective optical axes in parallel with one another. In this embodiment, the gap between each adjacent pair of the image-capturing units **1201** to **1203** is R. The horizontal angle of view of the image-capturing unit **1201** is θ1, and the vertical angle of view thereof is φ1. The horizontal angle of view of each of the image-capturing units **1202**, **1203** is θ2, and the vertical angle of view thereof is φ2. In other words, the image-capturing unit **1202** and the image-capturing unit **1203** have the same angles of view. Note that the horizontal angles of view satisfy θ1>θ2, and the vertical angles of view satisfy φ1>φ2. Thus, the image-capturing unit **1201** has wider angles of view than the image-capturing units **1202**, **1203**. As the user presses the image-capturing button **1204**, the image-capturing units **1201** to **1203** receive light at their sensors (image-capturing devices) as optical information on an object. The optical signals thus received are A/D converted, and a plurality of pieces of captured image data are captured simultaneously. A distance L from the image-capturing apparatus **1200** to the object calculated based on the focus settings at the time of the image capture and the like is attached to each piece of the captured image data as tag information. In the following, captured images represented by the pieces of captured image data captured by the image-capturing units **1201**, **1202**, **1203** will be denoted by I1, I2, I3, respectively.

With the multiple-lens image-capturing apparatus configured as above, it is possible to obtain a plurality of color images of the same object captured from a plurality of points of view. Note that although the number of image-capturing units is three here, the number of image-capturing units is not limited to three. The above is an example of the image-capturing apparatus in Embodiment 4.

Next, details of the virtual-angle-of-view-image-data generating process in Embodiment 4 will be described with reference to a flowchart shown in FIG. **13**.

First, in step S**1301**, an image-processing unit **212** generates image data corresponding to a point of view between the image-capturing unit **1202** and the image-capturing unit **1203** from a captured image I2 and a captured image I3 represented by pieces of captured image data **404** by using a parallax interpolation process. In other words, the image-processing unit **212** generates virtual-point-of-view image data from pieces of captured image data having the same angles of view. Specifically, the image-processing unit **212** generates virtual-point-of-view image data representing a virtual-point-of-view image I' corresponding to the point of view of the image-capturing unit **1201**. An existing method is utilized for the parallax interpolation process. For example, the virtual-point-of-view image I' corresponding to the point of view of the image-capturing unit **1201** may be generated based on the amount of parallax between each pair of corresponding pixels of the captured image I2 and the captured image I3 determined by performing block matching using the two images. Alternatively, the virtual-point-of-view image I' corresponding to the point of view of the image-capturing unit **1201** may be generated by associating characteristic points extracted from the two images and by performing a morphing process based on the correspondence between the characteristic points.

Then, in step S**1302**, the image-processing unit **212** determines weights to be applied to the captured image data **404** and the virtual-point-of-view image data for the virtual-angle-of-view image data **407** to be generated. Specifically, the image-processing unit **212** determines the weights based on the angles of view θ1, θ2 included in image-capture information **405** and a virtual angle of view θ' included in an image-processing parameter **406**. In Embodiment 4, the weights to be applied to the captured image I1 and the virtual-point-of-view image I' are determined. Note that details of this process are similar to those in step S**601**.

Then, in step S**1303**, the captured image I1 and the virtual-point-of-view image I' are aligned. Specifically, similarly to step S**602**, affine parameters a1 to a6 which indicate the positional relationship between the pixels (x, y) of the captured image I1 and the pixels (x', y') of the virtual-point-of-view image I' are determined. The difference from step S**602** is the method of determining ΔS, ΔT, and they are found by the following equations in this embodiment.

$$\Delta S = L\left(\tan\left(\frac{\theta 1}{2}\right) - \tan\left(\frac{\theta 2}{2}\right)\right) \quad (13)$$

$$\Delta T = L\left(\tan\left(\frac{\phi 1}{2}\right) - \tan\left(\frac{\phi 2}{2}\right)\right)$$

The affine parameters a1 to a6 determined as described above are stored into a storage device such as a RAM **202**.

Then, in step S**1304**, the image-processing unit **212** sets a virtual-angle-of-view area in the captured image I1 based on the virtual angle of view θ' included in the image-processing parameter **406**. Details of this process are similar to those in step S**603**.

Lastly, in step S**1305**, the image-processing unit **212** generates virtual-angle-of-view image data **407** representing a virtual-angle-of-view image from the captured image I1 and the virtual-point-of-view image I'. In step S**1305**, the virtual-angle-of-view image data **407** representing the virtual-angle-of-view image is generated by using the weights w1, w2 stored in step S**1302**, the affine parameters a1 to a6 stored in step S**1303**, and the affine parameters b1 to b6 stored in step S**1304**. Details of this process are the same as those in step S**604** except that I2 is I'.

By performing the processes described above, good virtual-angle-of-view image data **407** can be generated even from an object that has depth.

Embodiment 5

In Embodiment 4, the example is described in which good virtual-angle-of-view image data is generated from an object that has depth by generating a virtual-point-of-view image corresponding to the same point of view as a captured image and by using the captured image and the virtual-point-of-view image.

In Embodiment 5, first, a plurality of virtual-point-of-view images having different angles of view corresponding to a predetermined point of view are generated from captured images. Then, of the plurality of virtual-point-of-view images thus generated, virtual-point-of-view images having angles of view closer to a desired virtual angle of view are preferentially used to generate a virtual-angle-of-view image. In this way, the enlargement magnification of an image-enlargement process to be performed on each virtual-point-of-view image can be made small. Accordingly, it is possible to perform higher-magnification digital zoom than that in Embodiment 4 on an object having depth while suppressing decrease in the resolution of the image.

The difference between Embodiment 5 and Embodiments 1 to 4 is the image-capturing apparatus **100** and the virtual-angle-of-view-image generating process S**503**.

FIG. **14**A shows an example of the image-capturing apparatus in Embodiment 5. An image-capturing apparatus **1400** includes six image-capturing units **1402** to **1407** configured to obtain color images, and an image-capturing button **1408**. As shown in FIG. **14**B, the image-capturing units **1402** to **1407** are disposed in such a way as to have their respective optical axes in parallel with one another. In this embodiment, the gap between the image-capturing units **1402**, **1403** is R1, the gap between the image-capturing units **1404**, **1405** is R2, and the gap between the image-capturing units **1406**, **1407** is R3. Moreover, the horizontal angle of view of each of the image-capturing units **1402**, **1403** is θ3, and the vertical angle of view thereof is φ3, the horizontal angle of view of each of the image-capturing units **1404**, **1405** is θ2, and the vertical angle of view thereof is φ2, and the horizontal angle of view of each of the image-capturing units **1406**, **1407** is θ1, and the vertical angle of view thereof is φ1. Note that the horizontal angles of view satisfy θ1>θ2>θ3, and the vertical angles of view satisfy φ1>φ2>φ3. Thus, the image-capturing units **1406** and the image-capturing unit **1407** have the widest angles of view, and the image-capturing units **1402** and the image-capturing unit **1403** have the narrowest angles of view. Moreover, the image-capturing units having the same angles of view are disposed symmetrically about a virtual-point-of-view position **1401**.

As the user presses the image-capturing button **1408**, the image-capturing units **1402** to **1407** receive light at their sensors (image-capturing devices) as optical information on an object. The optical signals thus received are A/D converted, and a plurality of pieces of color image data (digital data) are captured simultaneously. A distance L from the image-capturing apparatus **1400** to the object calculated based on the focus settings at the time of the image capture and the like is attached to each piece of the color image data as tag information. In the following, captured images captured by the image-capturing units **1402**, **1403**, **1404**, **1405**, **1406**, **1407** will be denoted by I2, I3, I4, I5, I6, I7, respectively.

With the multiple-lens image-capturing apparatus configured as above, it is possible to obtain a plurality of color images of the same object captured from a plurality of points of view. Note that although the number of image-capturing units is six here, the number of image-capturing units is not limited to six. The above is an example of the image-capturing apparatus in Embodiment 5.

Next, details of the virtual-angle-of-view-image generating process in Embodiment 5 will be described with reference to a flowchart shown in FIG. **15**. In summary, first, three pieces of virtual-point-of-view image data of different angles of view corresponding to the virtual-point-of-view position **1401** shown in FIG. **14**A are generated from pieces of captured image data **404** by a parallax interpolation process. Then, virtual-angle-of-view image data is generated based on the three pieces of virtual-point-of-view image data. In the following description, the generation of virtual-point-of-view image data will be expressed simply as the generation of a virtual-point-of-view image for the sake of simple explanation. Likewise, the generation of virtual-angle-of-view image data will be expressed simply as the generation of a virtual-angle-of-view image. Now, the virtual-angle-of-view-image generating process will be described in detail with reference to the flowchart.

First, in step S**1501**, an image-processing unit **212** generates an image corresponding to a position between the image-capturing unit **1402** and the image-capturing unit **1403** from the captured images I2, I3 included in the captured image data **404** by using a parallax interpolation process. Specifically, the image-processing unit **212** generates a virtual-point-of-view image I1' corresponding to the virtual-point-of-view position **1401**. An existing method is utilized for the parallax interpolation process as in Embodiment 4.

Then, in step S**1502**, the image-processing unit **212** generates an image corresponding to a position between the image-capturing unit **1404** and the image-capturing unit **1405** from the captured images I4, I5 included in the captured image data **404** by using a parallax interpolation process. Specifically, the image-processing unit **212** generates a virtual-point-of-view image I2' corresponding to the virtual-point-of-view position **1401**. An existing method is utilized for the parallax interpolation process as in Embodiment 4.

Then, in step S**1503**, the image-processing unit **212** generates an image corresponding to a position between the image-capturing unit **1406** and the image-capturing unit **1407** from the captured images I6, I7 included in the captured image data **404** by using a parallax interpolation process. Specifically, the image-processing unit **212** gener-

ates a virtual-point-of-view image I3' corresponding to the position of the virtual-point-of-view position **1401**. An existing method is utilized for the parallax interpolation process as in Embodiment 4.

Then, in step **S1504**, the image-processing unit **212** calculates weights to be applied to the virtual-point-of-view images I1', I2', I3' for a virtual-angle-of-view image **407** to be generated, based on the angles of view θ1, θ2, θ3 and a virtual angle of view θ' included in image-captured information **405**. The weights to be applied to the virtual-point-of-view images I1', I2', I3' are denoted by w1, w2, w3, respectively. FIG. **16**A shows an example of the relationship between the virtual angle of view θ' and the weights w1, w2, w3. In FIG. **16**A, the weights w1, w2, w3 inside a range of θ1>θ'≥θ2 are such that the weights w1, w2 are suitably changed while the weight w3 is fixed at 0 and remains unchanged. Specifically, the weights w1, w2, w3 are described by the following equations.

$$w1 = \frac{\theta' - \theta 2}{\theta 1 - \theta 2} \qquad (14)$$
$$w2 = 1 - w1$$
$$w3 = 0$$

Moreover, inside a range of θ2>θ'≥θ3, the weight w1 is fixed at 0 and remains unchanged while the weights w2, w3 are suitably changed. Specifically, the weights w1, w2, w3 are described by the following equations.

$$w1 = 0 \qquad (15)$$
$$w2 = -\frac{\theta' - \theta 3}{\theta 2 - \theta 3}$$
$$w3 = 1 - w2$$

By setting the weights as described above, the virtual-angle-of-view image can be generated with larger weights applied to virtual-point-of-view images having closer angles of view to the virtual angle of view. In this way, the enlargement magnification of an image enlargement process to be performed on each virtual-point-of-view image can be made small. Accordingly, it is possible to perform high-magnification digital zoom on an object having depth while suppressing decrease in the resolution of the image.

Note that the method of calculating the weights w1, w2, w3 is not limited to the above method. As shown in FIG. **16**B, a threshold θτ1 and a threshold θτ2 set with respect to the virtual angle of view may be used to calculate the weights w1, w2, w3. The threshold θτ1 and the threshold θτ2 are recorded in a ROM **203** in advance and are utilized by loading them into a RAM **202** at the time of starting the image-processing apparatus. Specifically, the calculation of the weights w1, w2, w3 using the threshold θτ1 and the threshold θτ2 is described by the following equations.

$$w1=1, w2=w3=0 \quad (\theta' \le \theta\tau 1)$$
$$w2=1, w1=w3=0 \quad (\theta\tau 1 < \theta' \le \theta\tau 2)$$
$$w1=w2=0, w3=1 \quad (\theta\tau 2 < \theta') \qquad (16)$$

The above equations assume θ1>θτ1≥θ2 and θ2>θτ2≥θ3. The weighting shown in FIG. **16**B corresponds to the resolution priority mode in Embodiment 2. That is, by setting the threshold θτ1 equal to θ1 (θτ1=θ1), the virtual-point-of-view image I2' which has higher perceived resolution than the virtual-point-of-view image I1' can be preferentially used within a range of θ1>θ'≥θ2. Likewise, by setting the threshold θτ2 equal to θ2 (θτ2=θ2), the virtual-point-of-view image I3' which has higher perceived resolution than the virtual-point-of-view image I2' can be preferentially used within a range of θ2>θ'≥θ3. Accordingly, the perceived resolution of the virtual-angle-of-view image **407** can be improved. The weights w1, w2, w3 thus calculated are stored into a storage device such as the RAM **202**.

Note that in this embodiment, too, the above weight calculating method can be switched according to a mode selected by the user as described in Embodiment 2. Specifically, the weights in FIG. **16**B can be used in the resolution priority mode, and weights as shown in FIG. **16**A can be used in the noise-reduction priority mode.

Then, in step **S1505**, the image-processing unit **212** aligns the virtual-point-of-view images I1', I2', I3'. This alignment is performed for a plurality of sets of two images. Specifically, the alignment is achieved by combining alignment of the virtual-point-of-view images I1', I2' and alignment of the virtual-point-of-view images I2', I3'.

In the alignment of the virtual-point-of-view images I1', I2', they are associated with each other such that the object in the virtual-point-of-view image I1' and the object in the virtual-point-of-view image I2' overlap each other. Specifically, in the alignment, the pixels (x1',y1') of the virtual-point-of-view image I1' and the pixels (x2', y2') of the virtual-point-of-view image I2' are associated with each other by using affine parameters a1 to a6. The relationships between the pixels (x1', y1') and the pixels (x2', y2') and the affine parameters a1 to a6 are described by the following equations.

$$x2' = a1x1' + a2y1' + a3$$
$$y2' = a4x1' + a5y1' + a6 \qquad (17)$$

An example of the method of determining the affine parameters a1 to a6 will be described below. Here, the affine parameters a1 to a6 are calculated according to the following equations based on the angles of view of the virtual-point-of-view image I1', the angles of view of the virtual-point-of-view image I2', and the distance L to the object.

$$a1 = \frac{\tan(\theta 2/2)}{\tan(\theta 1/2)} \qquad (18)$$
$$a3 = s1$$
$$a5 = \frac{\tan(\phi 2/2)}{\tan(\phi 1/2)}$$
$$a6 = t1$$
$$a2 = a4 = 0$$

Here, as shown in FIG. **17**, s1, t1 correspond respectively to the distances from the area of the virtual-point-of-view image I2' in the virtual-point-of-view image I1' to ends of the virtual-point-of-view image I1' after the alignment, and can be found by the following equations.

$$s1 = \frac{W}{2L\tan(\theta 1/2)}\Delta S \qquad (19)$$

-continued

$$t1 = \frac{H}{2L\tan(\phi 1/2)}\Delta T$$

Here, W, H denote the size of the virtual-point-of-view image I1'. Moreover, ΔS, ΔT denote the lengths of cut portions the object and can be found by the following equations.

$$\Delta S = L\left(\tan\left(\frac{\theta 1}{2}\right) - \tan\left(\frac{\theta 2}{2}\right)\right) \quad (20)$$

$$\Delta T = L\left(\tan\left(\frac{\phi 1}{2}\right) - \tan\left(\frac{\phi 2}{2}\right)\right)$$

Next, the alignment of the virtual-point-of-view image I2' and the virtual-point-of-view image I3' will be described. The pixels (x2',y2') of the virtual-point-of-view image I2' and the pixels (x3', y3') of the virtual-point-of-view image I3' are associated with each other by using affine parameters a'1 to a'6 such that the object in the virtual-point-of-view image I2' and the object in the virtual-point-of-view image I3' overlap each other. The relationships between the pixels (x2', y2') and the pixels (x3', y3') and the affine parameters a'1 to a'6 are described by the following equations.

$$x3' = a'1x2' + a'2y2' + a'3$$

$$y3' = a'4x2' + a'5y2' + a'6 \quad (21)$$

An example of the method of determining the affine parameters a'1 to a'6 will be described below. Here, the affine parameters a'1 to a'6 are calculated according to the following equations based on the angles of view of the virtual-point-of-view image I2', the angles of view of the virtual-point-of-view image I3', and the distance L to the object.

$$a'1 = \frac{\tan(\theta 3/2)}{\tan(\theta 2/2)} \quad (22)$$

$$a'3 = s2$$

$$a'5 = \frac{\tan(\phi 3/2)}{\tan(\phi 2/2)}$$

$$a'6 = t2$$

$$a'2 = a'4 = 0$$

Here, s2, t2 correspond respectively to the distances from the area of the virtual-point-of-view image I3' in the virtual-point-of-view image I2' (not shown) to ends of the virtual-point-of-view image I2' after the alignment, and can be found by the following equations.

$$s2 = \frac{W2}{2L\tan(\theta 2/2)}\Delta S \quad (23)$$

$$t2 = \frac{H2}{2L\tan(\phi 2/2)}\Delta T$$

Here, W2, H2 denote the size of the virtual-point-of-view image I2'. Moreover, ΔS, ΔT denote the lengths of cut portions the object and can be found by the following equations.

$$\Delta S = L\left(\tan\left(\frac{\theta 2}{2}\right) - \tan\left(\frac{\theta 3}{2}\right)\right) \quad (24)$$

$$\Delta T = L\left(\tan\left(\frac{\phi 2}{2}\right) - \tan\left(\frac{\phi 3}{2}\right)\right)$$

The affine parameters a1 to a6, a'1 to a'6 calculated as described above are stored into the storage device such as the RAM **202**.

Then, in step S**1506**, the image-processing unit **212** sets a virtual-angle-of-view area in the virtual-point-of-view image I1' based on the virtual angle of view θ' included in an image-processing parameter **406**. Specifically, as shown in FIG. **18**, the image-processing unit **212** determines affine parameters b1 to b6 which indicate the relationship between the pixels (x1', y1') of the virtual-point-of-view image I1' and the pixels (x",y") of the virtual-angle-of-view image **407**. Equations therefor are shown below.

$$x1' = b1x'' + b2y'' + b3$$

$$y1' = b4x'' + b5y'' + b6 \quad (25)$$

An example of the method of determining the affine parameters b1 to b6 will be described below. Here, the affine parameters b1 to b6 are determined according to the following equations based on the angles of view of the virtual-point-of-view image I1', the angles of view of the virtual-angle-of-view image, and the size of the virtual-point-of-view image I1'.

$$b1 = \frac{W'}{W} \quad (26)$$

$$b3 = s3$$

$$b5 = \frac{H'}{H}$$

$$b6 = t3$$

$$b2 = b4 = 0$$

Here, W, H denote the width and height of the virtual-point-of-view image I1', respectively. W', H' denote the width and height of the virtual-angle-of-view area in the virtual-point-of-view image I1', respectively. Here, s3, t3 correspond respectively to the distances from the virtual-angle-of-view area shown in FIG. **18** to the ends of the virtual-point-of-view image I1', and can be found by the following equations, for example.

$$s3 = \frac{W}{2}\left(1 - \frac{\tan(\theta'/2)}{\tan(\theta 1/2)}\right) \quad (27)$$

$$t3 = \frac{H}{2}\left(1 - \frac{\tan(\phi'/2)}{\tan(\phi 1/2)}\right)$$

The affine parameters b1 to b6 determined as described above are stored into the storage device such as the RAM **202**.

Lastly, in step S**1507**, the image-processing unit **212** generates the virtual-angle-of-view image data **407** from the virtual-point-of-view images I1', I2', I3'. In step S**1507**, the virtual-angle-of-view image data **407** is generated by using the weights w1, w2, w3 stored in step S**1504**, the affine parameters a1 to a6, a' 1 to a' 6 stored in step S**1505**, and the affine parameters b1 to b6 stored in step S**1506**. Specifically,

the virtual-angle-of-view image **407** is generated by finding weighted means of the virtual-point-of-view image I1', I2', I3' according to the following equations.

$$I''(x'', y'') = \begin{cases} w1I1'(x1', y1') + & \\ w2I2'(x2', y2') + & \text{if}(x3', y3') \text{ is included in } I3' \\ w3I3'(x3', y3') & \\ w1I1'(x1', y1') + & \text{if}(x3', y3') \text{ is not included in } I3' \\ w2I2'(x2', y2') & \text{but}(x2', y2') \text{ is not included in } I2' \\ I1'(x1', y1') & \text{if}(x2', y2') \text{ is included in } I2' \end{cases} \quad (28)$$

Here, I" is the virtual-angle-of-view image data **407**. FIG. **19** schematically shows the correspondence between the virtual-angle-of-view image and the virtual-point-of-view images after the affine conversion processes. The pixels (x", y") of the virtual-angle-of-view image are determined from the pixels (x1', y1') of the virtual-point-of-view image I1' and the affine parameters b1 to b6. Moreover, the pixels (x2', y2') of the virtual-point-of-view image I2' corresponding to the pixels (x", y") of the virtual-angle-of-view image are determined from the corresponding pixels (x1', y1') of the virtual-point-of-view image I1' and the affine parameters a1 to a6. Furthermore, the pixels (x3',y3') of the virtual-point-of-view image I3' corresponding to the pixels (x", y") of the virtual-angle-of-view image are determined from the corresponding pixels (x2',y2') of the virtual-point-of-view image I2' and the affine parameters a'1 to a'6. The virtual-angle-of-view image data **407** thus generated is stored into the storage device such as the RAM **202**. By the above step, the virtual-angle-of-view-image generating process is finished.

By performing the processes described above, good virtual-angle-of-view image data **407** can be generated even from an object that has depth.

Moreover, in this embodiment, a virtual-angle-of-view image can be generated based on the virtual angle of view θ' within a range from the angle of view θ1 to the angle of view θ3. Accordingly, it is possible to perform high-magnification digital zoom as compared to the case where a virtual-angle-of-view image is generated based on the virtual angle of view θ' within a range from the angle of view θ1 to the angle of view θ2 by using captured images and a virtual-point-of-view image as described in Embodiment 4.

In FIG. **15**, the virtual-point-of-view images I1', I2', I3' are generated insteps S**1501** to S**1503**. Note, however, that the number of virtual-point-of-view images to be generated is not limited to three. Thus, in FIG. **14**B, it is possible to generate a virtual-angle-of-view image based on the virtual angle of view θ' within a range from the angle of view θ1 to an angle of view θ4 not shown.

It is the characteristic point of this embodiment that the use of a plurality of virtual-point-of-view images of different angles of view as described above enables high-magnification digital zoom while deterioration in the resolution of the virtual-point-of-view image due to an enlargement process is suppressed to a predetermined degree.

Note that in this embodiment, too, a virtual-angle-of-view image can be generated by using a captured image and a virtual-point-of-view image as described in Embodiment 4. Specifically, another image-capturing unit may be installed at the virtual-point-of-view position **1401**, and an image I1 obtained from the virtual-point-of-view position **1401** and the virtual-point-of-view image I1' may be used to generate a virtual-angle-of-view image.

Note that a virtual-angle-of-view image can be generated also by using all the virtual-point-of-view images I1', I2', I3'. This can be realized by, for example, setting the weights w1, w2, w3 to ⅓ in step S**1504**.

OTHER EMBODIMENTS

Embodiments of the present invention can also be realized by a computer of a system or apparatus that reads out and executes computer executable instructions recorded on a storage medium (e.g., non-transitory computer-readable storage medium) to perform the functions of one or more of the above-described embodiment (s) of the present invention, and by a method performed by the computer of the system or apparatus by, for example, reading out and executing the computer executable instructions from the storage medium to perform the functions of one or more of the above-described embodiment (s). The computer may comprise one or more of a central processing unit (CPU), micro processing unit (MPU), or other circuitry, and may include a network of separate computers or separate computer processors. The computer executable instructions may be provided to the computer, for example, from a network or the storage medium. The storage medium may include, for example, one or more of a hard disk, a random-access memory (RAM), a read only memory (ROM), a storage of distributed computing systems, an optical disk (such as a compact disc (CD), digital versatile disc (DVD), or Blu-ray Disc (BD)™), a flash memory device, a memory card, and the like.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2013-105157, filed May 17, 2013, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. An image-processing apparatus, comprising:

an obtaining unit configured to obtain first image data having a first angle of view obtained by image-capturing and second image data having a second angle of view smaller than the first angle of view, the second image data corresponding to the same viewpoint as the first image data, wherein the second image data has been generated using fourth image data and fifth image data each having the second angle of view and each captured from viewpoints different from each other; and

a generating unit configured to generate third image data, corresponding to the same viewpoint as the first and second image data, by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command, wherein the third image data has an angle of view that is smaller than the first angle of view but is larger than the second angle of view,

wherein the generating unit determines weights on the first image data and the second image data used for the weighted combination such that the closer the third angle of view is to the second angle of view, the larger the weight on the second image data is relative to the weight on the first image data, and

wherein the generating unit performs the weighted combination of the first image data and the second image data using the determined weights.

2. The image-processing apparatus according to claim **1**, wherein

the generating unit provides each of pixels of the second image data with a weight value corresponding to a distance from an end of the second image data to the pixel, and

the generating unit performs the weighted combination by further using the weight value corresponding to the distance from the end.

3. The image-processing apparatus according to claim **2**, wherein the generating unit determines the weight value corresponding to the distance from the end such that the longer the distance from the end, the larger the weight value is.

4. The image-processing apparatus according to claim **1**, wherein the generating unit aligns corresponding pixels of the first image data and the second image data and performs the weighted combination.

5. The image-processing apparatus according to claim **4**, wherein the generating unit performs the alignment based on the third angle of view, the first angle of view, and the second angle of view, positions of image-capturing units which have captured the first image data and the second image data, and a distance to an object.

6. The image-processing apparatus according to claim **4**, wherein the generating unit performs the weighted combination by applying the determined weights to the corresponding pixels of the first image data and the second image data.

7. The image-processing apparatus according to claim **1**, wherein the generating unit generates the third image data by adding at least part of the plurality of pieces of image data by using the weights.

8. The image-processing apparatus according to claim **1**, wherein the generating unit changes a standard for determining the weights according to a mode.

9. The image-processing apparatus according to claim **8**, wherein the generating unit is capable of a first mode in which the weights are continuously changed according to the third angle of view, and a second mode in which a threshold is set for the third angle of view and the weights are discontinuously switched before and after the threshold.

10. The image-processing apparatus according to claim **1**, wherein

the generating unit includes a correcting unit configured to correct the weights for each of areas of the third image data, and

the generating unit generates the third image data by using the weights corrected by the correcting unit.

11. The image-processing apparatus according to claim **10**, wherein the correcting unit corrects the weights based on a difference between the first image data and the second image data.

12. An image-capturing apparatus, comprising:

a first image capturing unit configured to capture first image data having a first angle of view;

a second image capturing unit configured to capture fourth image data having a second angle of view smaller than the first angle of view;

a third image capturing unit configured to capture fifth image data having the second angle of view, wherein the second image capturing unit and the third image capturing unit have viewpoints different from each other;

an obtaining unit configured to obtain the first image data and second image data, the second image data corresponding to the same viewpoint as the first image data, wherein the second image data has been generated using the fourth image data and the fifth image data; and

a generating unit configured to generate third image data, corresponding to the same viewpoint as the first and second image data, by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command, wherein the third image data has an angle of view that is smaller than the first angle of view but is larger than the second angle of view,

wherein the generating unit determines weights on the first image data and the second image data used for the weighted combination such that the closer the third angle of view is to the second angle of view, the larger the weight on the second image data is relative to the weight on the first image data, and

wherein the generating unit performs the weighted combination of the first image data and the second image data using the determined weights.

13. An image-processing method, comprising:

an obtaining step of obtaining first image data having a first angle of view obtained by image-capturing and second image data having a second angle of view smaller than the first angle of view, the second image data being image data corresponding to the same viewpoint as the first image data, wherein the second image data has been generated using fourth image data and fifth image data each having the second angle of view and each captured from viewpoints different from each other; and

a generating step of generating third image data, corresponding to the same viewpoint as the first and second image data, by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command, wherein the third image data has an angle of view that is smaller than the first angle of view but is larger than the second angle of view,

wherein in the generating step,

weights on the first image data and the second image data used for the weighted combination are determined such that the closer the third angle of view is to the second angle of view, the larger the weight on the second image data is relative to the weight on the first image data, and

the weighted combination of the first image data and the second image data is performed using the determined weights.

14. An image-capturing method, comprising:

a first capturing step of capturing first image data having a first angle of view;

a second capturing step of capturing fourth image data having a second angle of view smaller than the first angle of view;

a third image capturing step of capturing fifth image data having the second angle of view, wherein the second image capturing step and the third image capturing step is performed in viewpoints different from each other;

an obtaining step of obtaining the first image data and second image data, the second image data being image data corresponding to the same viewpoint as the first

image data, wherein the second image data has been generated using the fourth image data and the fifth image data; and

a generating step of generating third image data, corresponding to the same viewpoint as the first and second image data, by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command, wherein the third image data has an angle of view that is smaller than the first angle of view but is larger than the second angle of view,

wherein in the generating step,

weights on the first image data and the second image data in the weighted combination are determined such that the closer the third angle of view is to the second angle of view, the larger the weight on the second image data is relative to the weight on the first image data, and

the weighted combination of the first image data and the second image data is performed using the determined weights.

15. A non-transitory computer readable storage medium storing a program configured to cause a computer to execute an image-processing method, the image-processing method comprising:

an obtaining step of obtaining first image data having a first angle of view obtained by image-capturing and second image data having a second angle of view smaller than the first angle of view, the second image data being image data corresponding to the same viewpoint as the first image data, wherein the second image data has been generated using fourth image data and fifth image data each having the second angle of view and each captured from viewpoints different from each other; and

a generating step of generating third image data, corresponding to the same viewpoint as the first and second image data, by performing weighted combination of the first image data and the second image data, the third image data having a third angle of view determined according to a user command, wherein the third image data has an angle of view that is smaller than the first angle of view but is larger than the second angle of view,

wherein in the generating step,

weights on the first image data and the second image data used for the weighted combination are determined such that the closer the third angle of view is to the second angle of view, the larger the weight on the second image data is relative to the weight on the first image data, and

the weighted combination of the first image data and the second image data is performed using the determined weights.

16. An image-processing apparatus, comprising:

an obtaining unit configured to obtain first image data having a first angle of view obtained by image-capturing and second image data having a second angle of view smaller than the first angle of view, the second image data being image data corresponding to the same viewpoint as the first image data, wherein the second image data has been generated using fourth image data and fifth image data each having the second angle of view and each captured from viewpoints different from each other; and

a generating unit configured to generate a third image data, corresponding to the same viewpoint as the first image data and the second image data, using the first image data and the second image data which is digitally zoomed between the first angle of view and the second angle of view such that the first image data and the second image data change smoothly from one another.

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